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Detect Contained Subsurface Hazardous Waste

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NONDESTRUCTIVE TESTING (NDT) TECHNIQUES TO DETECT CONTAINED SUBSURFACE
HAZARDOUS WASTE

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Hazardous Waste Engineering Research Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs, and regulations of the Environmental Protection Agency, the permitting and other responsibilities of State and local governments, and the needs of both large and small businesses in handling their wastes responsibly and economically.

In this report, seventeen nondestructive testing (NDT) techniques are identified for potential use in locating buried metal or plastic containers at hazardous waste sites. The four most promising of these non-intrusive methods (electromagnetic induction, ground penetrating radar, magnetometry and metal detection) were exhaustively tested at typical, but simulated, sites. The results are relevant to the preparation of Reports of Investigation and Feasibility Studies (RI/FS), such as are required for CERCLA ("Superfund") assessments.

For further information, please contact the Land Pollution Control Division of the Hazardous Waste Engineering Research Laboratory.

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ABSTRACT

This project involves the detection of buried containers with NDT (remote-sensing) techniques. Seventeen techniques were considered and four were ultimately decided upon. They were: electromagnetic induction (EMI); metal detection (MD); magnetometer (MAG); and ground penetrating radar (GPR). The containers--both steel and plastic varying in size from 5 gal to 55 gal--were buried in known distributions in a wide variety of soils; also, some containers were submerged in water. Five diverse field sites were used.

As a result of the work at the five field sites, a relatively complete picture has emerged concerning the strengths and weaknesses of the four NDT subsurface container location techniques. Briefly it can be stated: GPR is the only reliable method to detect plastic containers, but it has limitations; GPR, EMI, and MD all suffer severe loss of detection ability when the background electrical conductivity exceeds 40 millimhos/meter; in a dry sandy soil EMI, GPR, and MAG are all capable of picking up a single 55-gal steel drum to a depth of at least 10 feet; the MAG method works well for steel under all subsurface conditions; and GPR can usually pickup the side walls of the excavations where waste is dumped. Application of signal enhancement techniques (background suppression) can be expected to enhance NDT utility.

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SECTION 1

INTRODUCTION

The release of hazardous materials into the environment is a real and potential problem of staggering proportions. The words Love Canal, "Valley of the Drums", kepone in the municipal water supply, Times Beach, National Priority List (NPL), etc., are everyday copy in the news media. A number of pieces of Federal legislation (and amendments thereto) have been passed in an attempt to combat this environmental problem. Among these are the 1972 Clean Water Act, the 1976 Resources Conservation and Recovery Act (RCRA) and the 1980 Comprehensive Environmental Response, Compensation, and Liability Act (Superfund). The Superfund bill was conceived as a mechanism to clean up existing hazardous waste sites. There are tens of thousands of such sites waiting to be cleaned-up and at least 700 on the NPL.

Even though there is no problem in identifying enough sites to remediate, it is most important to delineate the spatial extent of existing sites and to detect and determine the extent of potential (new) sites. The investigation of sub-surface objects (either buried beneath the ground surface or underwater) can be approached in two very different ways. The first type that generally comes to mind is by use of a suitable destructive test method. In this category are the following:

- test pits
- excavation trenches
- auger holes
- core borings
- observation wells.

While one does indeed "see" the subsurface materials as they are excavated for ease of examination and subsequent testing, such methods are not without drawbacks in identifying and locating buried containers. Some disadvantages of using destructive test methods for this purpose are:

- The information obtained is discontinuous over the area investigated.
- Permission to enter the properties in question (and excavate therein) may be troublesome or impossible to obtain.
- Access for excavation equipment may not be available at the site in question.
- Costs are generally high, e.g., small amounts of excavation can easily be \$200/cu. yd and boring costs of \$10/ft are not uncommon.¹
- There is a danger to personnel from containers containing hazardous, toxic, or radioactive materials that have been inadvertently ruptured or pierced by the excavations or borings.
- There is a danger to the environment due to such materials leaking from the containers if these have been ruptured or pierced.

¹The most common engineering units will be used. A conversion chart which makes the transformation to MKS or SI units is found in Appendix A.

The second type of approach to identifying and locating buried containers is by use of suitable non-destructive testing (NDT) methods, which is the subject of this paper. Within this category are the following methods, which have been used or seem to have applicability:

- seismic reflection
- seismic refraction
- electrical resistivity
- electromagnetic induction [EMI]
- induced polarization
- eddy current [metal detection (MD)]
- magnetometer (MAG)
- continuous microwave
- pulsed radio frequency [ground penetrating radar (GPR)]
- infrared radiation
- sonar (pulse echo acoustics).

All of the above methods are not equally suited for use in the hazardous waste area but many are. The interest in these NDT approaches to the problem seems to be increasing. At this time, the major disadvantage seems to be one of non-familiarity, a feature that this work is aimed at overcoming.

This report is divided into several distinct sections. Sections 2 and 3 deal with the conclusions and recommendations, respectively. Section 4 presents a brief, overall view of the types of existing NDT techniques which may be applicable to existing hazardous waste problems. Section 5 discusses literature searches on NDT methods and identifies those that appear worthy of field trials involving the location of buried hazardous waste containers. Section 6 deals with the results of the field trials, and covers the use of the most promising NDT methods in a number of specific hazardous waste situations.

SECTION 2

CONCLUSIONS

The objective of this project was to critically evaluate nondestructive testing (NDT) methods for applicability in locating buried containers of hazardous materials at dumpsites. Only non-intrusive methods were evaluated, e.g., those that did not require boring or coring. Seventeen NDT methods, including common geo-physical methods (seismic reflection, penetrating radiation, infrared radiation, self potential, electrical resistivity, pulse-echo ultrasonics, etc.) were selected for evaluation.

A critical literature survey showed that only seven have promise; the others, in general, lacked sufficient definition for the drum-sized containers being considered. The seven include: seismic refraction, electrical resistivity, continuous wave microwave, ground penetrating radar (GPR), metal detection (MD), electromagnetic induction (EMI), and magnetometer (MAG).

The conclusions drawn from comprehensive field work are that only the last four (GPR, MD, EMI, MAG) were sufficiently promising for detailed evaluation at five significantly different dumpsite environments, namely: dry, natural, interference-free, sandy soil (metal and plastic containers); saturated silty clay soil with significant interferences from above- and below-grade metal objects and nearby structures (metal containers); a river of varying electrical conductivity (metal containers submerged); a sandy soil of varying electrical conductivity (metal containers buried on a beach from the ocean to inland); and a sandy soil ocean beach (buried plastic containers).

Table 1 summarizes the results obtained at each of the five field sites using each of the four selected methods (GPR, MD, EMI, MAG) and, as such, may be used as a guide for practitioners when selecting equipment. Some additional remarks are in order to help in assimilating all the results of this project.

In a dry, granular soil with minimum interference, individual typical steel containers can easily be seen to a depth of at least 10 ft with all methods except MD, which detects to 6 ft. Deeper detection is probably possible, but 10 ft was the limit of our burial ability. As the soil water electrical conductivity becomes larger, the detection ability of the MD, EMI and GPR methods suffer. When the background conductivity rises to 40 millimhos/meter or above, the detection ability is very seriously impaired. The MAG method works well under all granular soil conditions, for it is not affected by high background electrical conductivity.

In cohesive soils, there are definite problems with MD, EMI and GPR due to the usual high water content and soil inhomogeneities. A logistical problem arises with respect to the MAG data, since work in cohesive soils was performed in the presence of much magnetic interfering material (trucks, fences, etc.). Research should be conducted in an interference-free cohesive soil using the MAG method. Also of interest would be the utility of MD, EMI and GPR in relatively uniform, dry cohesive soils.

Table 1.- General Acceptability of Using Various NDT Methods to Locate Typical Sized Buried Containers under Conditions Listed (Maximum Penetration Depth Achieved in Present Studies in Parentheses)

Steel Containers						
Subsurface Material (Reference)	Saturation	Type of Void Water	Metal Detector (MD)	Electromagnetic Induction (EMI)	Ground Penetrating Radar (GPR)	Magnetometer (MAG)
Granular (sand)	0% - 20%	fresh	excellent (6')	excellent (10')	excellent (10')	excellent (10')
	20% - 50%	intermediate	excellent (2')	average (4')	excellent (3')	excellent (4')
	50% - 100%	ocean	not good	not good	poor (2')	excellent (10')
Cohesive (clay)	50% - 100%	fresh	moderate* (4')	moderate* (4')	moderate* (4')	poor (4')**
Water	100%	fresh	excellent (3')	excellent (3')	excellent (4')	excellent (3')
	100%	intermediate	poor	not good	not good	excellent (3')
	100%	ocean	not good	not good	not good	excellent (3')
Plastic Containers						
Granular	10% - 50%	intermediate	not good	not good	excellent - if contents conductive (4'+) fair - if contents non-conducting.	not good
	50% - 100%	ocean	not good	not good	poor	not good

*Excellent in dry clay.

**Many interfering magnetic objects. Excellent in absence of interference.

When steel containers were submerged under water, the MD, EMI and GPR methods are only of value in relatively fresh water. When the water conductivity rises above about 100 millimhos/meter, the three methods are quite useless. The MAG method functions well in water in all conductivities.

Plastic containers are more difficult to detect than steel containers. The MD, EMI and MAG methods are quite useless in detecting buried plastic containers. The GPR methods works well for typical size plastic containers, especially if these are filled with electrically conductive material. However, the method still works with non-conductive contents. These results for plastic containers only apply for granular soil with relatively low electrical conductivity. If the granular soil has high conductivity material in its voids or if the soil is a wet, non-uniform cohesive material, then the same limitations apply to GPR as were mentioned earlier.

As a brief summary to be used in connection with Table 1, it can be stated that:

- MD, EMI and MAG all work extremely well in detecting buried steel containers in dry, granular soil of low electrical conductivity to any typical depth (i.e., easily to six feet).
- The MAG method works well under all subsurface conditions for steel containers.
- MD, EMI and GPR all suffer severe loss of detection ability when the soil's electrical conductivity rises above about 40 millimhos/meter. The same type figure also applies to the detection ability for containers submerged under water, i.e., when the conductivity of the water rises much above this value, detection is impossible.
- GPR is the only reliable method to detect buried plastic containers in sandy soil, but suffers in high conductivity and/or heterogeneous soils.
- For a preliminary survey of a metal-container dump site, the MD (instrument cost = \$500) is a good first method, followed closely by the MAG method (cost = \$4000). More detailed surveys can use the more expensive instruments (EMI cost = \$8000 and GPR cost = \$30,000).
- GPR can "see" excavation boundaries. This is an extremely important point when mapping out the boundaries of a "dump site."
- The contents of a steel container essentially have no effect on the detection ability with any of the methods. However, for plastic containers, contents of high conductivity are easier to observe (except for the MAG method).

SECTION 3

RECOMMENDATIONS

The four designated NDT techniques are definitely recommended for field use at hazardous waste sites, and indeed they are already being used. The use of the various techniques in the survey stages of the remedial cleanup work should be most helpful for engineering decisions. Also this type of work will afford an excellent check on the ultimate usefulness of NDT methods, as subsequent excavations will give "ground truth" information.

The suggestions as to the use of the NDT techniques are as follows:

- The MD should be used first to determine the gross spatial extent of the buried metal.
- The EMI and MAG methods should be next used for better spatial (and depth) definition.
- The GPR should be used to obtain the excavation trench boundaries and to obtain better definition of the waste and location of the water table in amenable soils.

A main area of additional research should be the use of commercial signal processing equipment in an attempt to effectively use GPR in the more hostile subsurface situations. These situations are steel containers in inhomogeneous silty and clayey soils (both wet and dry) and plastic containers in all types of soils.

Work on the use of NDT techniques in gravels (wet and dry) should be undertaken.

The effect on NDT techniques of actual organic and other industrial sludges at waste sites should be determined from field use of the methods.

SECTION 4

POSSIBLE NDT METHODS WHICH CAN BE USED TO HELP SOLVE HAZARDOUS MATERIALS WASTE PROBLEMS²

Books by Dobrin (1976), Griffith and King (1965), Grant and West (1965) and Sharma (1976) can be consulted for a general background on the use of the more traditional geophysical probing techniques. Additional references will be given as required. The following list is a reasonably complete list of techniques, and certainly encompasses a great many of the possible NDT methods pertinent to the hazardous materials waste problem. Each method is discussed briefly here and in more detail in Section 5.

4.1 Microwaves (Pulsed) [Ground Penetrating Radar (GPR)]

A short (a few microseconds long) pulse of microwave energy of carrier frequency between 0.1 and 1 GHz is sent into the ground. A reflection occurs when a media of different dielectric constant is encountered (e.g., a buried metal drum). The time it takes for the pulse to travel down and back gives an indication of the depth of the object. (Figure 1.) Lateral surveying gives an indication of the spatial extent of the objects. Systems are commercially available; surveys to at least 5 feet in depth (much deeper in very dry soils) can be quickly made over relatively large areas. [See Cook (1972, 1974), Moffatt and Puskar (1976), Rosetta (1977) and Morey (1974) for further details.] This pulsed microwave method is also called ground penetrating (probing) radar, i.e., GPR.

4.2 Microwaves (Continuous)

This method is quite similar to pulsed microwaves except that a continuous wave (CW) is used. The CW is swept in frequency and the wave from the ground surface and the wave from a subsurface reflection interfere with each other. The spacing (in frequency) between interference maxima (or minima) as the frequency is swept gives the depth of the reflecting surface. (See Figure 2.) The systems are not commercially available. [See Lundien (1971, 1972) and Okrasinski, et al. (1978, 1979) for further details.]

4.3 Eddy Current [Metal Detection (MD)]

This NDT method utilizes a search coil with an alternating current (AC) flowing through it. This produces an AC magnetic field which induces eddy currents in a nearby metallic object. In turn these eddy currents produce a magnetic moment in the metal which then interacts back (via mutual inductance) on the search coil. The size of this mutual inductance is read out and gives an indication of the presence and size of the metallic object. This is the principle on which most metal detectors work. There are a wide variety of these metal detectors commercially available (Figure 3.)

²An attempt is made here to indicate a very wide range of techniques. Obviously all techniques cannot be fully researched in the experimental phase of the program.

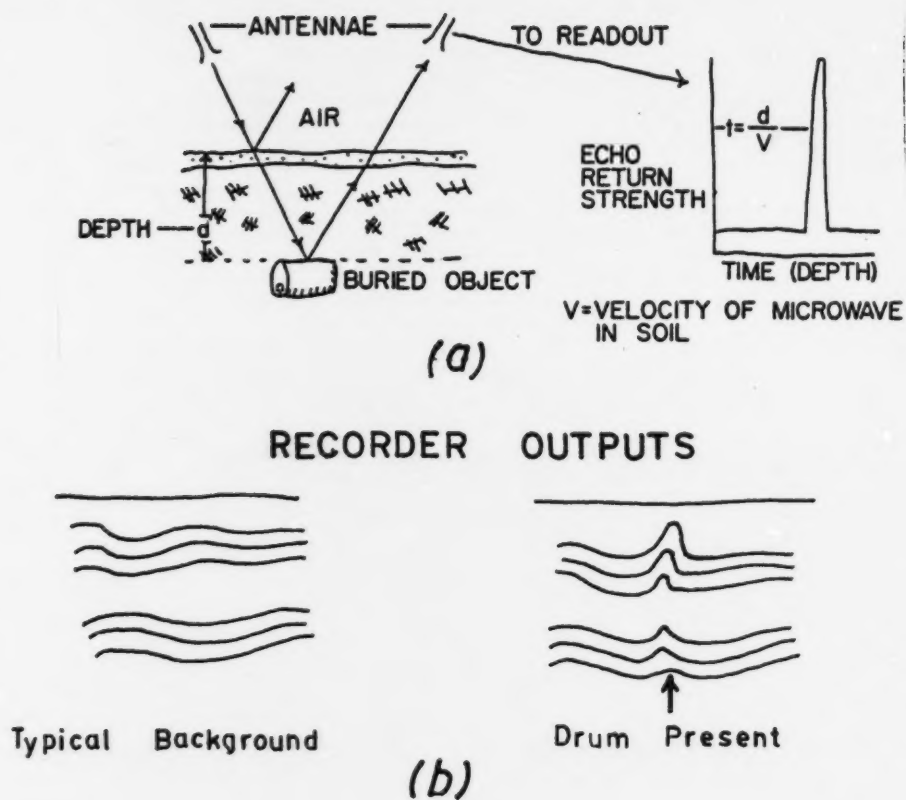


Figure 1 - Principles of Ground Penetrating Radar.

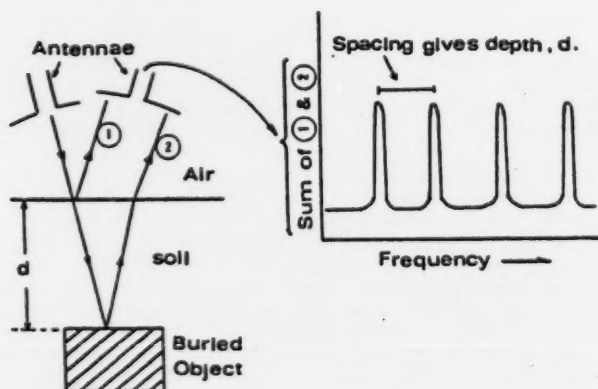


Figure 2 - Principles of Continuous Microwave Interference.

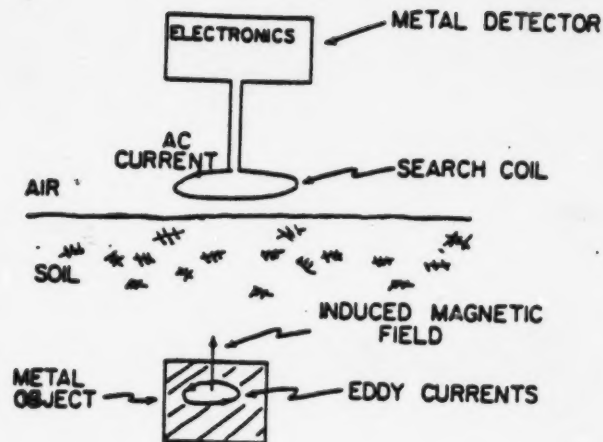


Figure 3 - The Eddy Current or "Metal Detector" Method.

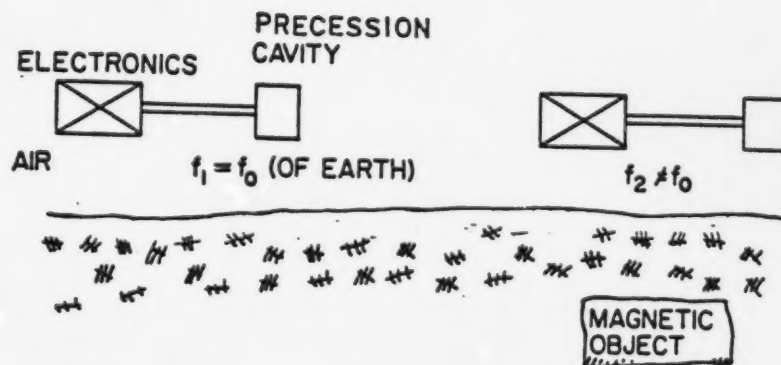


Figure 4 - The Proton Precession Magnetometer.

Eddy current techniques are also widely used to determine the nature and integrity of metallic surfaces and this may be of value in determining the integrity of deteriorated drums, tanks, etc.

4.4 Magnetometer (MAG)

A magnetometer is a device which measures very minute changes in the earth's magnetic field. Any magnetic object, e.g., an iron ore deposit, buried steel object, etc., will alter the earth's magnetic field locally and thus can potentially be detected. The most common magnetometer today uses proton precession. (See Figure 4.) The nuclear spin of the proton can be made to precess in a steady magnetic field. The frequency of the precession is proportional to the magnetic field. (As an aside, the reader might note that the precession of the earth about its axes of rotation causes the change of seasons.) If a magnetic object is encountered the local magnetic field (and hence the magnetic precession frequency) changes, indicating a deviation from the "earth-only" value. Magnetometers of several types are commercially available.

A new, very sensitive magnetometer based on the superconducting Josephson effect, and called SQUID, is now commercially available, but is presently too sophisticated for field use.

4.5 Seismic Reflection

This standard geophysical method utilizes a mechanical impulse (hammer blow, explosion, etc.) that is generated in the ground at a given point, either on the surface or below. The elastic (seismic) waves emanating from this source are picked up via a series of transducers on the surface. If a well-defined subsurface layer or layers are present, there will be a characteristic series of return echoes. (Figure 5.) It is possible that a buried object could be located this way by examining the response versus the transducer location at various distances. This technique has not been used extensively to detect small buried objects, but is very widely used in the oil and mineral prospecting area. Commercial equipment is readily available, but has not been successfully applied to the buried container problem.

4.6 Seismic Refraction

A related geophysical method is that in which a mechanical impulse is applied to the ground and the time to reach a transducer is measured for varying transducer-to-impulse distances. The time is plotted as a function of distance and, if there is a well-defined layer beneath the surface, a characteristic break in the curve is found from which the depth to the layer can be determined. (Figure 6.) This method has not been used to detect small objects, but is widely used in the oil and mineral prospecting area and in geotechnical engineering. A great deal of commercial equipment is available.

4.7 Electrical Resistivity

This geophysical method applies current to the ground through electrodes; its operation depends on the fact that any subsurface variation in conductivity alters the form of the current flow within the earth. Therefore, the distribution of electric potential is affected. The degree to which the

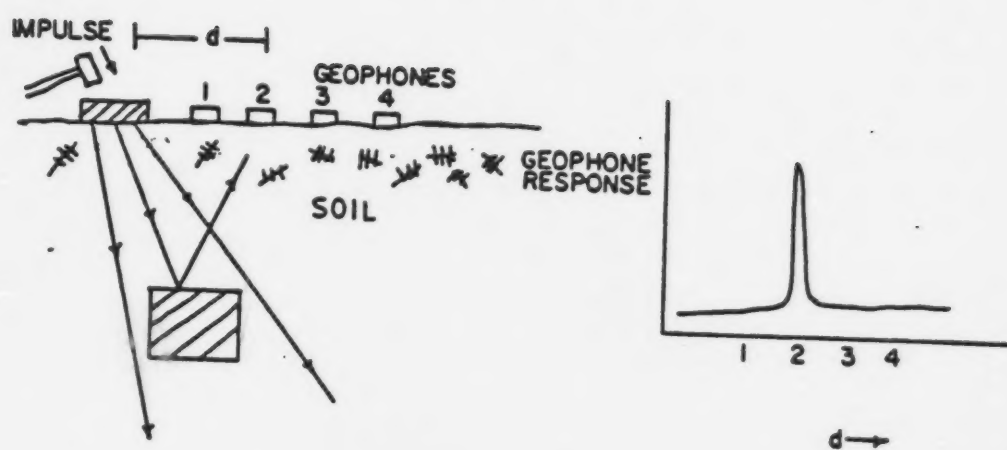


Figure 5 - Principles of Seismic Reflection.

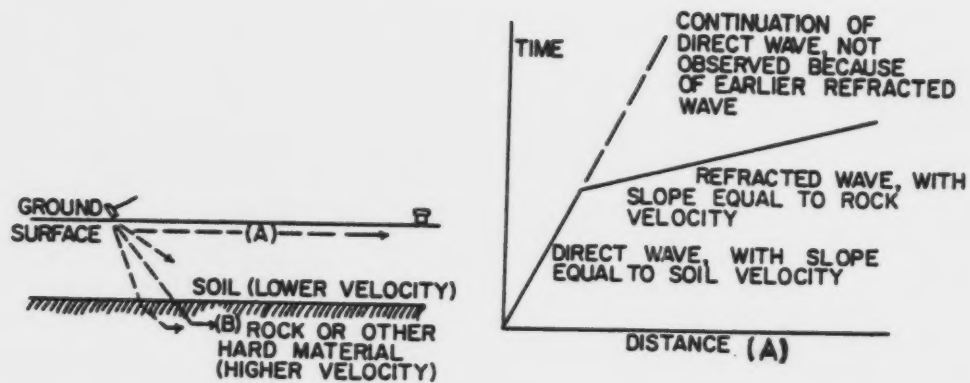


Figure 6 - Principles of Seismic Refraction.

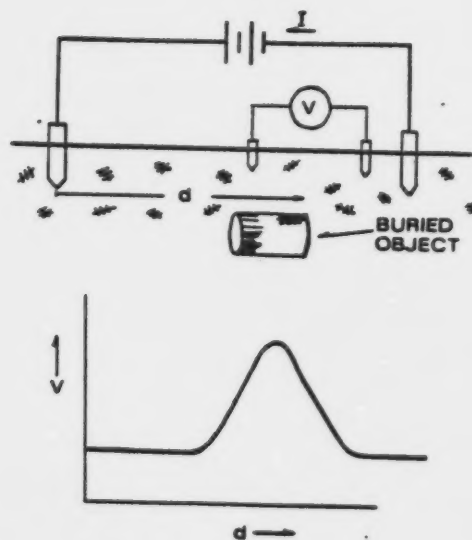


Figure 7 - The Electrical Resistivity Technique.

potential at the surface is affected depends on the size, shape, location, and electrical resistivity of the subsurface mass. (Figure 7.) It is therefore possible to obtain information about the subsurface distribution of various bodies from potential measurements made at the surface. This method - like the seismic approaches - is used extensively in the oil and mineral prospecting area and in geotechnical engineering but has not been widely or very successfully used in shallow monitoring for small buried objects. There are many commercial sources of equipment from which to choose.

4.8 Penetrating Radiation

This NDT method is similar to a chest X-ray where the absorption pattern of X-rays indicates the configuration of the chest. Here, penetrating radiation (X-rays, γ -rays, or neutrons) is passed through the material and the spatial density of the received pattern indicates defects. (See Figure 8.) This is widely used as an NDT technique in the materials area and may be of help in determining the integrity of drums, containers, etc. Many types of commercial equipment are available, but none are readily applicable to buried object location.

For subsurface pollution tracing, it might be possible to neutron activate the soil to a certain depth and then use the back scatter γ -radiation to analyze for various elements. This method is probably quite difficult (and dangerous, as well as publically sensitive) because of the high neutron intensities needed and the strong attenuation in the soil, but it should probably be investigated. [See Iddings, et al. (1979), McGonnagle (1961) and Sharpe (1970) for further details.] Neutron activation analysis is widely used in laboratories and readily provides elemental composition data.

4.9 Acoustic Emission

As an NDT method, acoustic emission makes use of the fact that a material placed under stress, subsequently deforms, and generates noise (sounds). The monitoring of the noises, called acoustic emissions, is accomplished by sensing them with a transducer (which converts sound, i.e., elastic vibrations, into electrical signals), then amplifying, filtering, counting, and/or recording the resulting signals. The total acoustic emission counts, or count rate, is then related to the stress causing the emissions for an assessment of the materials' integrity and stability. (Figure 9.) The method has been used successfully in monitoring the stability of earth dams, many types of pressure vessels, and a great many other structures. A number of firms supply acoustic emission instrumentation. [See Koerner, et al. (1978a, b) for further details.]

4.10 Liquid Penetrant

The surface to be evaluated in this method is covered with a penetrating liquid that infiltrates surface connected cracks. The excess liquid is then removed from the surface and a powder coating is applied. Subsequently, the liquid in the cracks bleeds out to stain the powder thereby tracing the defect. (See Figure 10.) The method is a widely used NDT technique and a considerable amount of commercial equipment is available. [See Iddings, et al. (1979), McGonnagle (1961) and Sharpe (1970).]

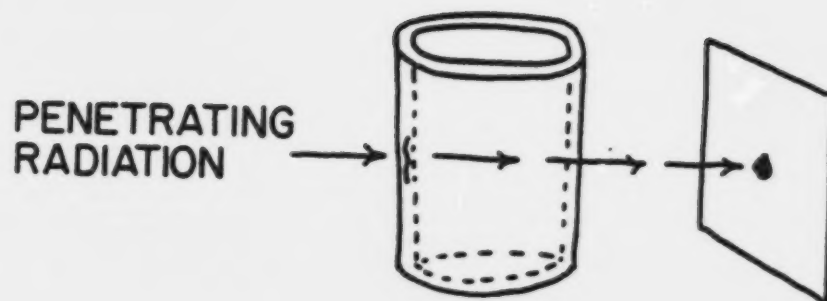


Figure 8 - The Use of Penetrating Radiation.

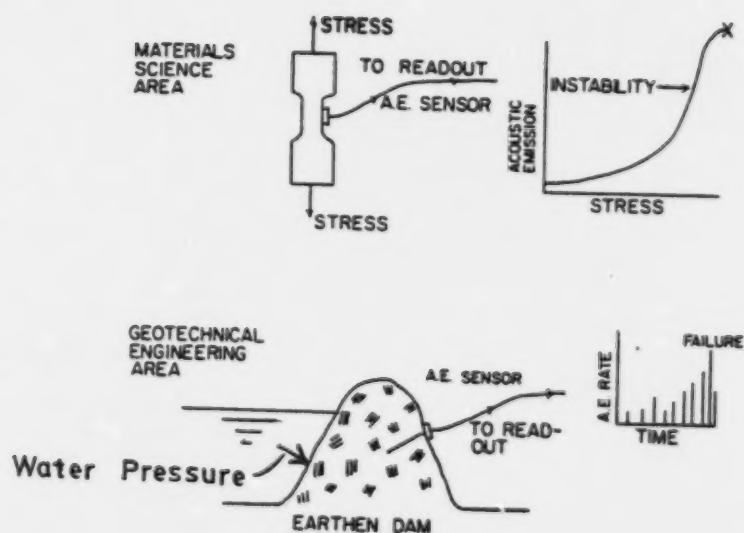


Figure 9 - Principles of Acoustic Emission.

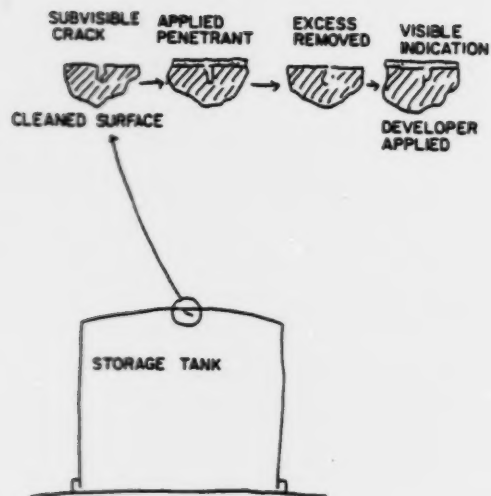


Figure 10 - Principles of the Liquid Penetrant Method.

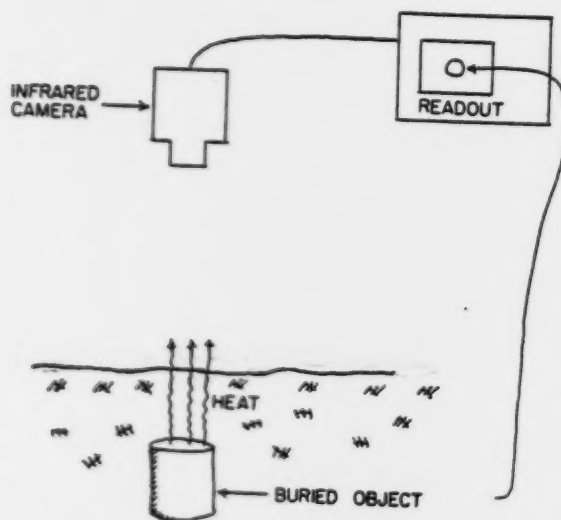


Figure 11 - The Infrared Radiometry Method.

4.11 Infrared Radiometry

The method utilizes thermal radiation from a heated surface which is measured by an infrared radiometer. The heating can be either active or ambient. The radiation pattern reveals heat flow anomalies caused by imperfect structural properties and flaws. (See Figure 11.) The method is a highly refined NDT method. Much commercially available equipment has been used to determine buried objects, water flow profiles (in dams), heat escaping from uninsulated houses, heat from vegetation, etc. [See Sharpe (1970) and Leftwich and Ordway (1970) for further details.]

4.12 Pulse-Echo Ultrasonics

In this NDT method a pulse of elastic energy is beamed into the material to be investigated. The pulse is typically a few microseconds long and has a carrier frequency of about 1 MHz. The elastic wave is reflected from cracks and discontinuities within the material. The nature of the reflected pattern gives an indication of the depth and spatial extent of cracks and discontinuities. (See Figure 12.) The method is well developed [see McGonnagle (1961) and Sharpe (1970)] and there is a great deal of commercially available equipment on the market.

4.13 Sonar

This method uses a pulse of acoustic energy of about 12 KHz carrier frequency to probe the bottom of water bodies. One needs to immerse the sound source in water for good coupling so the method is limited to looking under water. (See Figure 13.) The method could be adapted to search for abandoned dump sites which have subsequently been submerged, and for possible "sinker chemicals." [See Van Reenan (1964).] The low frequency limits detection to relatively large buried containers or objects.

4.14 Electromagnetic Induction (EMI)

A transmit coil generates an electromagnetic field and a receiving coil in the vicinity picks up the resulting field. Some of the field arrives via the air and some via the subsurface material. The field through the air is essentially constant for a given transmitter-receiver distance but the field arriving from the subsurface material depends on the subsurface electrical conductivity. If a conducting body is present in the subsurface material between the two coils, the total detected field is altered and the anomaly noted. (See Figure 14.)

Many such devices are commercially available. [See McNeil (1980)]. [See HRB-Singer (1971) for details of the method when the drive field is supplied by already existing signals in the subsurface.]

4.15 Induced Polarization

Induced polarization techniques utilize a strong primary current which polarizes the subsurface strata and produces a potential field which persists after the current circuit is interrupted. The intensity of this potential field and its decay time are the parameters usually measured. (See Figure 15.) Field and laboratory experiments show that buried metallic conductors,

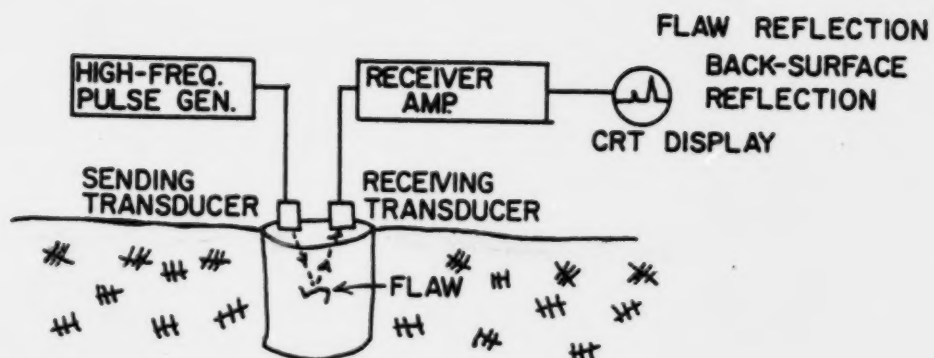


Figure 12 - Principles of Pulse-Echo Ultrasonics.

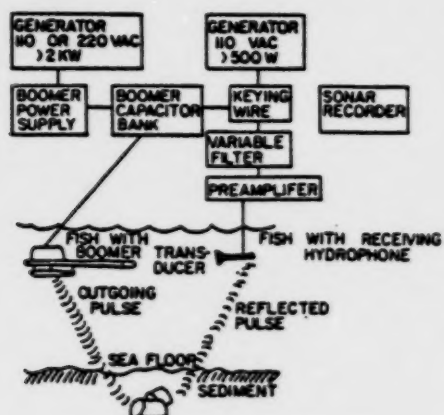


Figure 13 - Principles of Water Bottom Profiling Using Sonar.

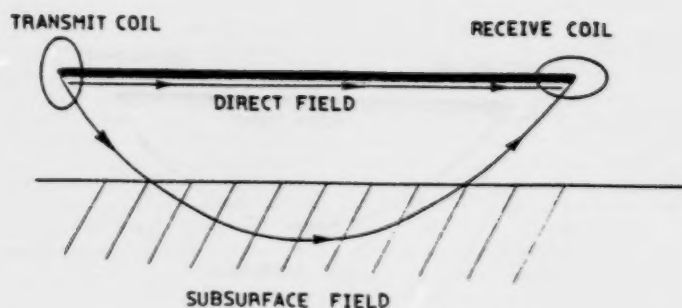


Figure 14 - The Electromagnetic Induction (EMI) Method.

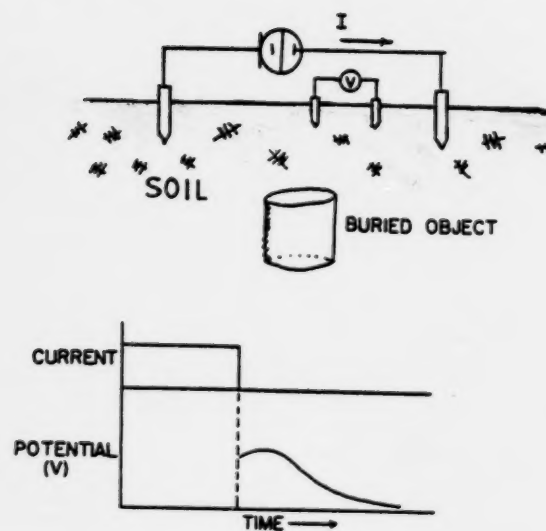


Figure 15 - Principles of the Induced Polarization Technique.

such as sulfide ore bodies, will produce substantial induced polarization effects measurable on the surface if the conductors are not buried too deeply. Other experiments have shown that ionic exchange in clays and similar phenomena in water-saturated sediments will also produce sizeable induced polarization effects. [See HRB-Singer (1971) for further details.]

The induced polarization methods can produce unique responses from buried metallic conductors and water-saturated rocks. They do not inherently have any better depth penetration or resolution than resistivity or electromagnetic methods. The best equipment used in the application of this method is at least one order of magnitude more sensitive than the equipment used in resistivity surveys.

4.16 Self-Potential

Self-potential methods are based on the measurement of potential differences due to currents generated by electrochemical actions such as salt-concentration gradients, filtering action of certain materials, particularly clays, flow of fluids through porous rocks, and chemical reactions between minerals and pore-filling fluids. (See Figure 16.) The degree to which such potentials are produced or modified by buried objects is not well-known. The method, originally developed by the Russians, is being used to a limited extent by geophysicists in the U. S. and is further described in HRB-Singer (1971).

4.17 Optical Techniques

One possible method to look at the sinker chemical problem would be with the LIDAR (Light Detection and Ranging) technique. Here a laser beam would scatter from the sinker layer and the scattered radiation would be analyzed for the Raman lines of the particular pollutant. (See Figure 17.) This method would allow large areas to be monitored quickly. There are probably other optical methods which could also fall into this particular category. [See Kent, et al. (1970).]

In Section 5 the individual NDT techniques will be discussed further, with the goal of deciding whether to evaluate them in more detail in the experimental phase of the program.

It is interesting (at least historically) to see where the author's ideas were very early in the project after brief review of the various NDT methods. Table 2 gives a matrix of problem areas versus the NDT technique(s) which might be brought to bear on them for detection and delineation. In constructing Table 2, the authors did not have available detailed literature searches on the various methods or actual experience with the actual methods in the field. Hence, the final ranking matrix (Section 6) will look decidedly different from that shown in Table 2.

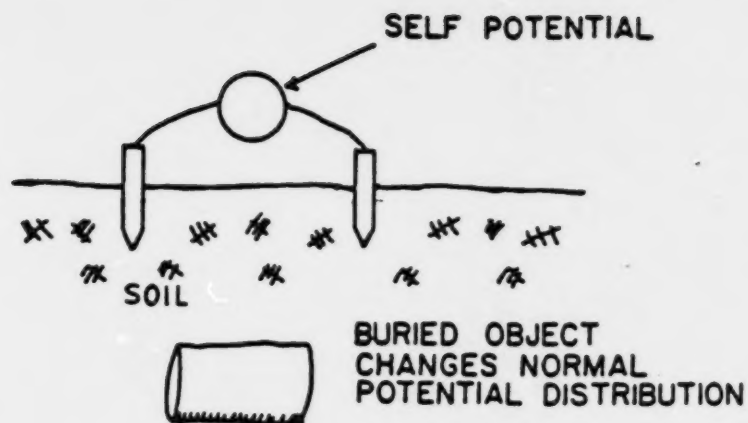


Figure 16 - The Self Potential Technique.

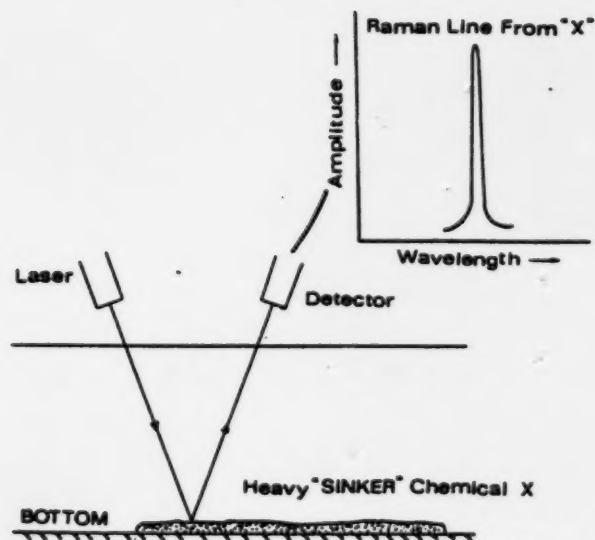


Figure 17 - Optical Technique to Detect "Sinker" Chemical on the Bottom of Waterways.

Table 2.- EPA Problem Areas Rated Against Possible NDT Method of Solution (Very preliminary work) (1 - highest potential success; 5 - lowest potential success, no entry -not applicable)

Problem areas	(a) Dike Sta- bility	(b) Deep Depth Tracing	(c) Shallow Depth Tracing	(d) Surface Container Corrosion	(e) Buried Container Location	(f) Buried Container Stability	(g) Buried Pipe- line	(h) "Sinker" Chemicals
NDT Method								
1. Pulsed Micro-wave (GPR)	3	2	2		1			
2. CW Micro-wave (CWM)	4	2	2		1			
3. Eddy Current (MD)				2	2	2		
4. Magneto-meter (MAG)				5	3	4		
5. Seismic Reflection	4	4	4		5			
6. Seismic Refraction (SR)	4	4	4		5			
7. Electrical Resistivity (ER)	4	3	3		5			
8. Penetrating Radiation		4	4	5		5		
9. Acoustic Emission	1			4			1	
10. Liquid Penetrant								
11. Infrared Radiation	5	4	4		4	4	3	
12. Ultrasonics		5	5	1		2	2	
13. Sonar					5		5	3
14. VLF Electro-magnetic (EMI)					5			
15. Induced Polarization					5			
16. Self Potential	5	5	4				4	
17. Optical (Laser)								1

SECTION 5

DETAILS OF LITERATURE SEARCHES ON EACH NDT METHOD

Each NDT method to be described in this Section was the subject of a detailed report submitted to our contract monitor. (The reports are listed in Appendix A). As such, these individual reports (a total of 30 were written) should be considered as an integral part of this Final Report and be consulted as needed.³ For each NDT method considered, the rationale will be given for either eliminating the method from further consideration or for continuing on with experiments (for further evaluation). In most cases where further work seemed justified, the complete details and references concerning the method will be found in this Section and in Section 6. The comments concerning each NDT method follow.

5.1 Microwave-Pulsed [Ground Penetrating Radar (GPR)]

At the time of the literature search evaluation (1980-1981) of the pulsed microwave method, quite a bit of pertinent work has already been performed using this method. Table 3 from Lord, et. al (1980) gives a review of such work up to 1980. Clearly this method is a prime candidate for further use and evaluation in regards to detecting and delineating hazardous material spills and leaks and buried containers.

5.2 Microwave Continuous

At the time of the evaluation of the method a certain amount of work had been done using the continuous microwave method. See Table 4 from Lord, et al. (1980). The work however was not as pertinent to the hazardous materials spills areas as the pulsed microwave. In fact it appeared that only the Drexel group was pursuing its use in such a direction. Certainly the previous pertinent work done with the method warranted field trials.

5.3 Eddy Current [Metal Detector (MD)]

The use of metal detectors to detect coins at the beach, weapons in airports, etc., definitely placed this technique in the category of further experimental evaluation. Eddy current units are also available to look for cracks and other defects on metallic surfaces. Thus the literature search delved deeply into the possibility of using eddy current techniques to monitor the integrity of metallic containers either on the surface or of ones that had been uncovered during excavation. The literature search showed quite convincingly that the very rough and dirty (contaminated) surfaces involved here would not allow the eddy current method to be used to determine surface mechanical integrity. The literature search did show, however, that eddy currents are effective in locating buried metal containers.

³A number of articles based on the present work have appeared in Conference Proceedings and Journals. (Refer to the Reference Section.)

Table 3, - Current Applications of Pulsed GPR Technique

Investigator(s)	Approximate Frequency Range (MHz)	Maximum Depth (Meters)	Major Application Area
Cook (1972,1974)	1-100	225	locating faults, walls, holes
Rosetta (1977)	100-200	15	locating faults, caverns, water, utilities
Morey (1974)	100-200	15	locating faults, caverns, water, utilities
Dolphin, et al. (1974)	15-50	40	locating rock cavities
Unterberger (1977)	230	500	salt thickness measurement
Harrison (1970)	35	2000	determining ice thickness
Rubin, et al. (1976)	100-200	10	detecting subway tunnels
Rubin and Fowler (1978)	100-200	15	drilling guidance, subway tunnel monitoring, coal thickness
Benson and Glaccum (1979a, 1979b)	100-200	10	general subsurface probing, locate and follow pollutants in ground, detection of buried containers of industrial wastes
Sandness, et al. (1979)	100-200	10	general subsurface probing
Alongi (1973)	1,000	3	locating mines, pavement thickness, shallow voids, pipelines

Table 3. - Current Applications of Pulsed GPR Technique - Continued

Investigator(s)	Approximate Frequency Range (MHz)	Maximum Depth (Meters)	Major Application Area
Moffatt and Puskar (1976)	6,000	3	locating faults, joints, cavities, pipelines
The Drexel Group Koerner, et al. (1981a, 1981b, 1976-1981, 1981) Lord (1980)	300	4	detection of buried containers and pipelines, water table seepage

Table 4 - Current Applications of Continuous Wave Microwave Technique

Investigator(s)	Approximate Frequency Range (MHz)	Maximum Depth (Meters)	Major Application Area
El Said (1956)	0.08-0.9	800	detection of water levels in Egyptian desert
Annan (1973)	0.5-50	2000	probing ice sheets and salt layers
Lytle, et al. (1979)	10-70	(between boreholes)	bore-hole to bore-hole propagation to detect tunnels
Laine, et al. (1978)	1-100	(between boreholes)	geotomographic analysis of concrete integrity
Unterberger (1974)	4300	150	salt thickness measurements
Holser, et al. (1972)	4300	150	salt thickness measurements
Lundien (1972)	250-8000	3	defining subsurface layers
Ellerbruch and Adams (1974)	500-5000	3	determining coal layer thickness
The Drexel Group Koerner, et al. (1978b), Okrasinski, et al. (1978), Koerner, et al. (1979), Lord (1980), Koerner, et al., (1981b)	500-4000	4	detection of ground water, top of rock, buried containers and pipelines, subsurface cavities

5.4 Magnetometer (MAG)

Magnetometers of various forms have been used for a long time to search for magnetic ore bodies (e.g. iron ore). Due to the extreme sensitivity of modern-day magnetometers, they should have significant potential in searching for magnetic (e.g., steel) containers. Some brief reports of work using magnetometers to search for buried steel containers were available at the time of the literature search. Thus the magnetometer was a prime candidate for further experimental evaluation.

5.5 Seismic Reflection

This method is used a great deal in the oil and mineral prospecting areas, which involves distances (km) much larger than the ones involved in container or seepage plume locations (m). The reflection method (as opposed to the refraction method) has not been used much at all in the geotechnical field. No reports were available where the method was used directly in container or plume location. Also the refraction method was picked for further evaluation, so the reflection method was dropped from further consideration.

5.6 Seismic Refraction

This method, is used extensively in surveys to attempt to find oil and mineral deposits. It is also used in geotechnical engineering for much shorter range subsurface profiling. There were no reports of its use in container or plume location,⁴ but due to its relatively wide-spread use in the geotechnical field, the availability of equipment, and the possibility that it could detect extensive burials of drums, it was decided to evaluate the method further in the experimental portion of the program.

5.7 Electrical Resistivity

This method, another geophysical tool for oil and mineral prospecting, was selected for further evaluation in the experimental work for exactly the same reasons as seismic refraction.

5.8 Penetrating Radiation

This method has been used for many years to detect integrity of metal objects and the integrity of joining operations, such as welds. Thus the integrity of containers could possibly be determined with penetrating radiation. The method was eliminated from further consideration due to:

- high costs of necessary equipment
- rigid safety precautions needed to minimize danger
- NDT techniques with better chance of return for time spent.

⁴The method has use in determining subsurface structure, which can be of help in defining plume movement direction.

5.9 Acoustic Emission

Of all the possible problem areas, listed in Table 2, only dike stability and pipelines leaks can be looked at with acoustic emission. The authors have already completed an EPA-sponsored project on the use of acoustic emission to determine dike stability. The authors have also been active in the use of acoustic emission in pipe line and storage tank leaks. Hence this technique was eliminated from further consideration in this particular project.

5.10 Liquid Penetrant

As in the case of eddy current examination of metallic surfaces, the liquid penetrant needs relatively clean surfaces. Considering the rather "dirty" condition of surface or recently-exposed subsurface drums this method was not considered further.

5.11 Infrared Radiometry

In principle, buried containers or seepage plumes beneath the surface lead to characteristic temperature gradients on the surface. The literature search uncovered no attempts to observe this particular type of substructure detail.

While one of the authors (AL) was on sabbatical leave at Cornell University in 1980 he had access to a very sophisticated infrared system. A simple experimental program was undertaken where containers (heated and unheated) were buried in a small sand box (6' x 3' x 1') and also heated water streams were passed through the subsurface material. In no case were any infrared surface effects observed, even though the experiments were designed to accentuate the thermal effects.

Also a simple calculation is presented in Appendix C, which indicates that slightly heated (or cooled) buried containers will be extremely difficult to observe with state-of-the-art infrared equipment.

For these reasons, the use of infrared techniques were not considered further in the project.

5.12 Pulse-Echo Ultrasonics

This is a very widely used NDT technique in the metals area, and to a certain extent in other areas (concrete, plastics, etc.). The only area where the conventional technique could possibly be used would be in the integrity testing of surface, or recently-uncovered containers.⁵ Owing to the very poor surface quality and the very thin walls on most of these containers, it was decided that conventional ultrasonics did not hold significant promise in the assigned hazardous material areas.

⁵The attenuation of ultrasound (frequencies of about a megahertz) in soil is so large that any use in soil is completely prohibited.

5.13 Sonar

The "sonar" method, even though using lower frequencies than ultrasonic pulse-echo, still suffers from the extreme attenuation in soils (at any frequency above a KHz or so). There has been some limited success using the method [Van Reenan (1964)] - see Figure 18 (reproduced directly from the article by Van Reenan), but very little pertinent work has been reported. It was decided not to pursue this method further, even though it could have use in identifying containers under water.

5.14 Electromagnetic Induction (EMI)

The literature search indicated that this method had definite promise, as work was reported where successes had been achieved finding buried containers and leachate plumes. Therefore the method was considered for further experimental evaluation.

5.15 Induced Polarization

The literature search turned up no short range (on a few meters scale) uses of the technique. This, plus the very limited access to the equipment, served to eliminate the method from further consideration.

5.16 Self-Potential

Very little work of any kind has been reported using this method. Also no commercial equipment dedicated to this measurement is available as far as the the authors are aware. For these reasons, the method was not considered for further evaluation.

5.17 Optical Techniques

This method has definite potential in identifying "sinker" chemicals in shallow, clear water. However there is no background work and/or data in regard to this particular use of optical techniques and the authors have no background at all in optical measurements. Due to the large amounts of time and money needed to be able to proceed, and the limited nature of the problem, it was felt that effort and resources could be better expended on more worthwhile NDT techniques. Therefore the optical techniques were eliminated from further consideration. Of the methods eliminated during the literature phase, the optical techniques seemed to be the one with the most promise.

Therefore the methods that survived the literature evaluation phase of the project and were to be evaluated experimentally (with the problem of subsurface container detection and delineation) were:

- Ground Penetrating Radar (GPR)
- Microwaves (continuous) (MCW)
- Eddy Current - Also called Metal Detector (MD)
- Magnetometer (MAG)
- Seismic Refraction (SR)
- Electrical Resistivity (ER)
- Electromagnetic Induction (EMI)

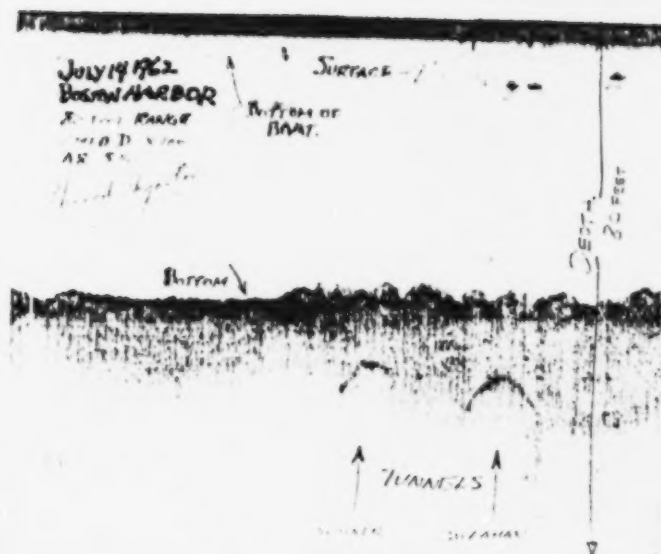


Figure 18 - Detection of Tunnels Below Boston Harbor using 12 KHz Sonar
[Directly after Van Reenan (1964) which accounts for poor
quality, but the figure is important for this review].

SECTION 6

EXPERIMENTAL EVALUATION OF THE DESIGNATED NDT TECHNIQUES AT VARIOUS FIELD SITES

6.1 Evaluation of the NDT Techniques at a Dry Sandy Soil Site with Little Interference ("Best Possible" Site)

The literature search results, described in Section 5, indicated that seven NDT techniques were worthy of further experimental evaluation to detect buried containers. Presented in this Section are the results of field tests at a "best possible" field site, where the seven techniques were cut down to four [Lord, et al., (1982)].

6.1.1 Site Details

The site where the containers were buried was an abandoned sand quarry which was left in a level condition free of all vegetation and miscellaneous construction debris. No pipelines, cables or overhead wires were within 1,000 ft. of the site. The closest road was also 1,000 ft. from the site, thus, background noise from man-made objects was minimal.

Disturbed and undisturbed soil samples indicated that the site consisted of a very uniform, poorly-graded sand (specific gravity of 2.65, effective size of 0.18 mm, and coefficient of uniformity of 3.4). Its average in situ density is 101 PCF (porosity of 0.40), which results in a relative density of 73 percent.

For the purposes of this study, it is important to note that the in situ water content is only 2 percent, which corresponds to a degree of saturation of 8 percent, i.e., the sand is almost dry. The water table at the site was estimated to be 20 ft. deeper than the ground surface and the sand, with essentially no capillary zone, proved to be nearly ideal for the tests.

The containers were placed in hand-excavated and equipment-excavated holes varying from 1 ft to 14 ft. in depth. Containers placed in the excavations varied in size from 2 gallons to 55 gallons and were made from both steel and plastic. The container burial patterns were as follows:

- Four steel containers (2, 5, 30, 55 gallons) buried at constant depths of 3.5 ft. (i.e., 3.5 ft. of soil cover)
- Four 30-gallon steel containers buried at 1-ft., 3-ft., 6-ft. and 11-ft. depths
- Four 55-gallon steel containers buried at 4.5-ft depth in two groups, one by itself, and the other three side by side
- Three 30-gallon steel containers buried at 3-ft depth, but at different orientations, i.e., 0°, 45°, 90°
- Two plastic containers buried at 2-ft depth, one filled with fresh water, the other filled with salt water
- A random burial site approximately 12 ft x 12 ft x 5 ft deep, which was filled with six steel drums and two plastic drums of various sizes and a few steel plates of various sizes. (This pattern was called the

"Trash dump.")

All patterns were separated by sufficient distance so that interaction between them was relatively unlikely, and within each pattern sufficient distance was allowed for the same reason.

6.1.2 Results

Due to the large size of the study, only one pattern will be described fully. Others will be referred to in a general table to follow. The particular pattern to be discussed consists of four 55-gallon steel containers placed empty and on their sides in two groups. One container was placed by itself, and the other three touching one another and located 16 ft from the first. The tops of the containers were placed 4.5 ft beneath the surface and backfilled with the same sand that was taken from the excavation. The results of the seven NDT methods are presented below.

Figure 19 shows the results of a seismic refraction survey. A commercially-available, geotechnical engineering type instrument was used. Figure 19(a) indicates a SR survey where no buried drums were present. Figure 19(b) shows the survey over the site of the four buried containers. It is observed that no characteristic features occur in the vicinity of the drums and that the two curves are essentially the same.

The data in Figure 20 are from the electrical resistivity survey using a conventional, commercially-available instrument. The very large dip in conductivity at 44 ft is due to a very small dry gully where water runs during rainstorms. Again no characteristic structure is present near the location of the four buried drums.

Figure 21 shows ground probing radar scans using a commercially-available instrument. The characteristic parabolic signatures of cylindrical reflectors are easily seen. (Refer to Fig. 1 for a schematic interpretation.) The depths are read as 4 and 4.5 feet, very close to the actual depths.

The continuous wave microwave results are shown in Figure 22. The unit used was developed at Drexel University (Koerner, et al., 1978b). There are anomalies at the approximate location of the drums, but in both cases the calculated depths are significantly less than the actual depths.

Figure 23 shows the metal detector results using a sophisticated commercial unit. The drums were easily detected above background noise level, but no depths can be estimated using this technique.

Figure 24 gives the results of the electromagnetic induction scan using a high-quality commercial unit. The drums are very easily detected and located, even when the scans are not directly taken over the buried containers. No depths can be easily determined using this technique.

The results of the magnetometer scans are indicated in Figure 25. A commercially-available proton precession unit was employed. Again the drums are easily detected and located, even when the scans are displaced laterally

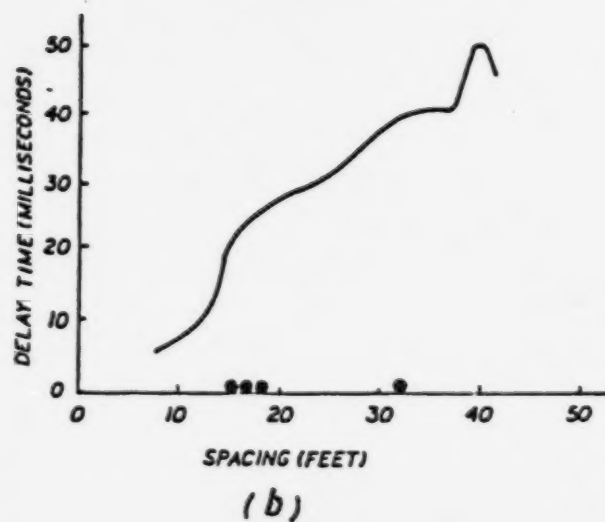
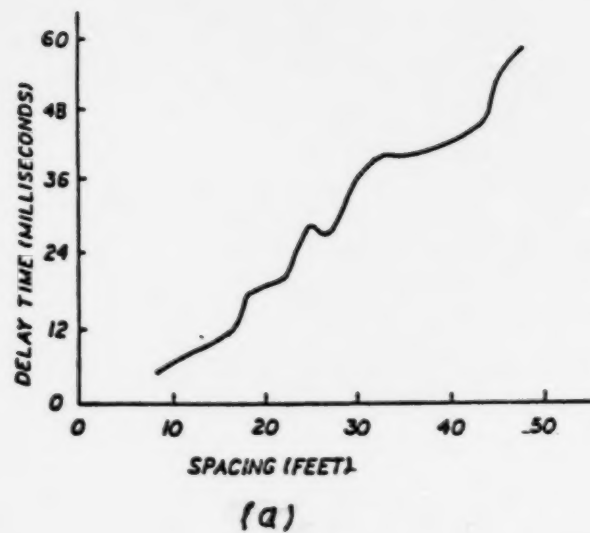


Figure 19 - Seismic Refraction Survey Response; (a) no drums present, (b) four 55-gal steel drum pattern (one and three) at 4-1/4 feet of soil cover.

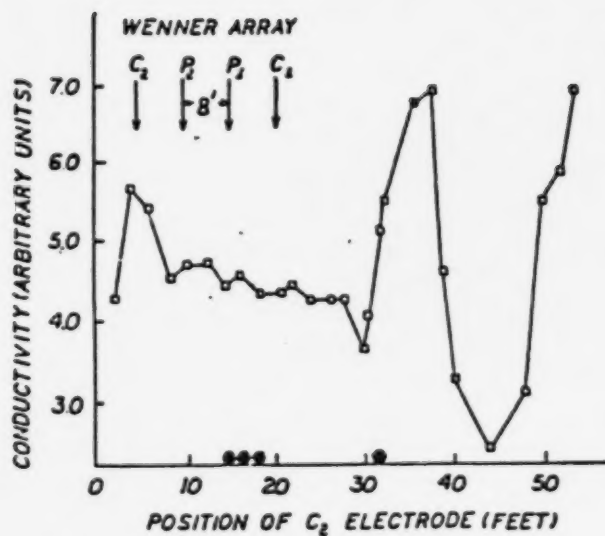


Figure 20 - Electrical Resistivity Survey Response Over Four-Drum Pattern (Four 55-gal. steel drums at 4-1/2 feet of soil cover).

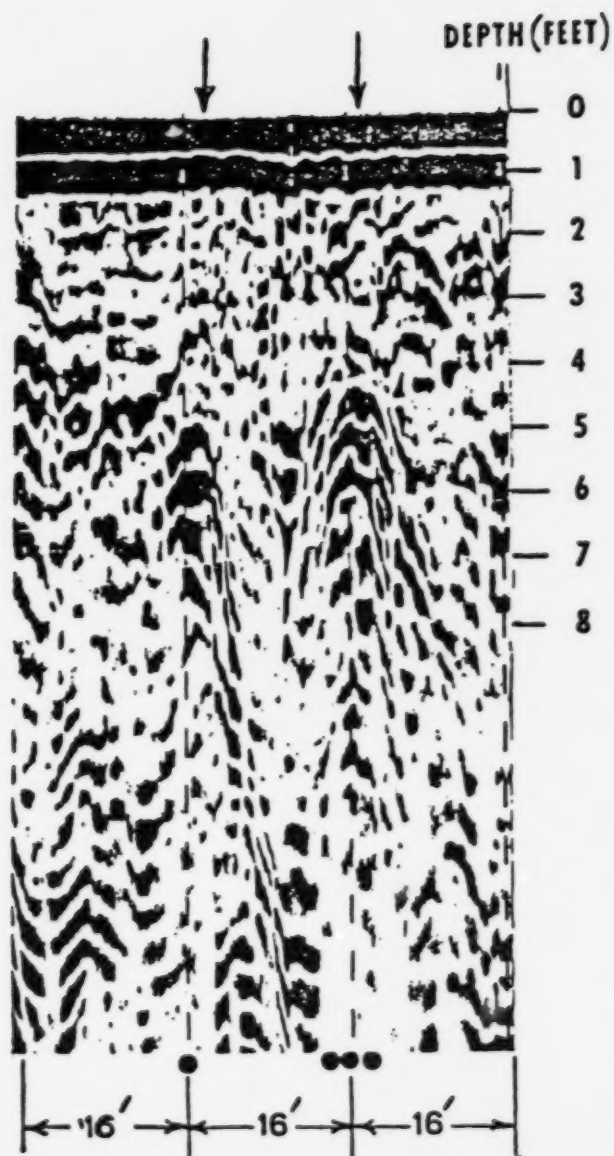


Figure 21 - Ground Probing Radar Results Over the Four Drum Pattern (Four 55-gal. steel drums at 4-1/2 feet of soil cover).

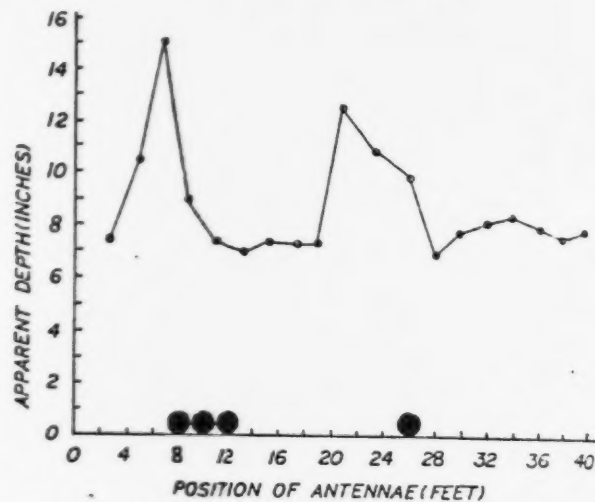


Figure 22 - Continuous Wave Microwave Results for the Four Drum Pattern (Four 55-gal. steel drums at 4-1/2 feet of soil cover).

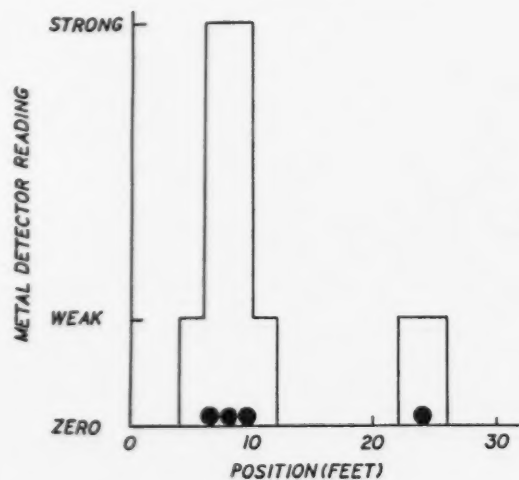


Figure 23 - Metal Detector Results Over the Four Drum Pattern (Four 55-gal. steel drums at 4-1/2 feet of soil cover).

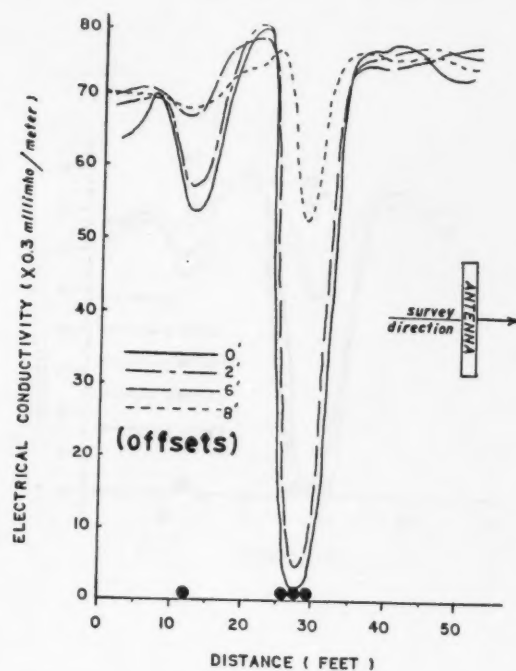


Figure 24 - Electromagnetic Induction Scans Over the Four Drum Pattern (Four 55-gal. steel drums at 4-1/2 feet of soil cover).

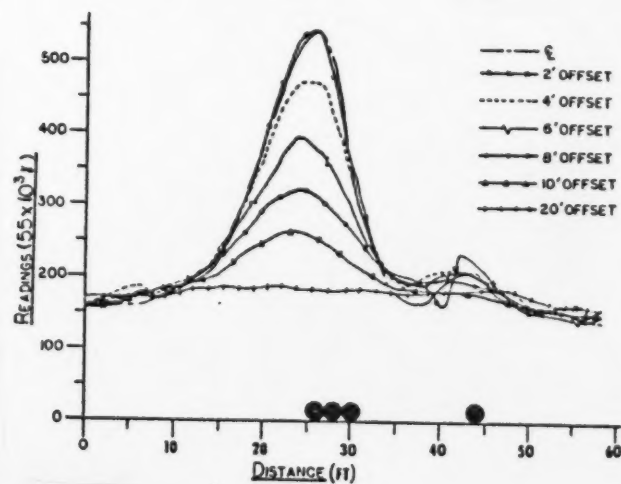


Figure 25 - Magnetometer Scans Over the Four Drum Pattern (Four 55-gal. steel drums at 4-1/2 feet of soil cover).

from the center line of the drums. No depths can be easily determined using this technique.

Due to length limitations, only the generalized results of the other container patterns are presented (Table 5). By necessity, they are presented on a qualitative basis but the table gives an idea of the effectiveness of each NDT method under each test pattern condition. Complete details are given in journal articles (Bowders, et al., 1982; Tyagi, et al. 1983a; Tyagi, et al., 1983b; Tyagi, et al., 1983c.) Especially important here is the ability of GPR to detect the excavation boundaries of the trash dump. (See Figure 26.)

6.1.3 Discussion

The entire study cannot be discussed in detail, so the results from the entire study are presented as concisely as possible in Table 6. Only ground probing radar, metal detection, electromagnetic induction, and magnetometer methods are mentioned since continuous wave microwave was of marginal use and seismic and resistivity methods were of no use.

The major observations (after this first study) with regard to NDT use for buried container detection and location can be stated as follows:

1. The metal detector is very inexpensive, easy to use, and quite sensitive to metal drums.
2. Magnetometer and EMI both will work well with only metal drums, while the magnetometer obviously works only for drums made from magnetic materials (for example, steel).
3. GPR is the only technique which will detect plastic drums (as well as metal) and also give the depth of the buried object. It has detected a 30-gallon steel drum at 11 ft of sand cover. It can detect excavation boundaries.
4. CW microwave appears to be of marginal value until such time as commercially made instruments are available.
5. Conventional seismic refraction and electrical resistivity are of little use.

6.2 Evaluation of Four NDT Techniques at a Site with Saturated Silty Clay Soil

The experimental work at the "best possible" site (Section 6.1) reduced the number of techniques from seven to four. These four techniques were next evaluated at a much more "hostile" field site. This site was in the yard of a construction company where much magnetic and electrically-conductive interference was present (trailers, fences, utility lines, etc.). The soil was also not as forgiving to the various NDT techniques as was the first site. It was a saturated silty clay soil and much less homogeneous than the ideal site's sandy soil. Due to the higher water content, the GPR, EMI and MD all suffered from attenuation (damping) effects. The results of this work were presented at the 1982 Conference on Management of Uncontrolled Hazardous Waste Sites in Washington, DC, Nov. 29-Dec. 1, 1982 (Koerner, et al. 1982b).

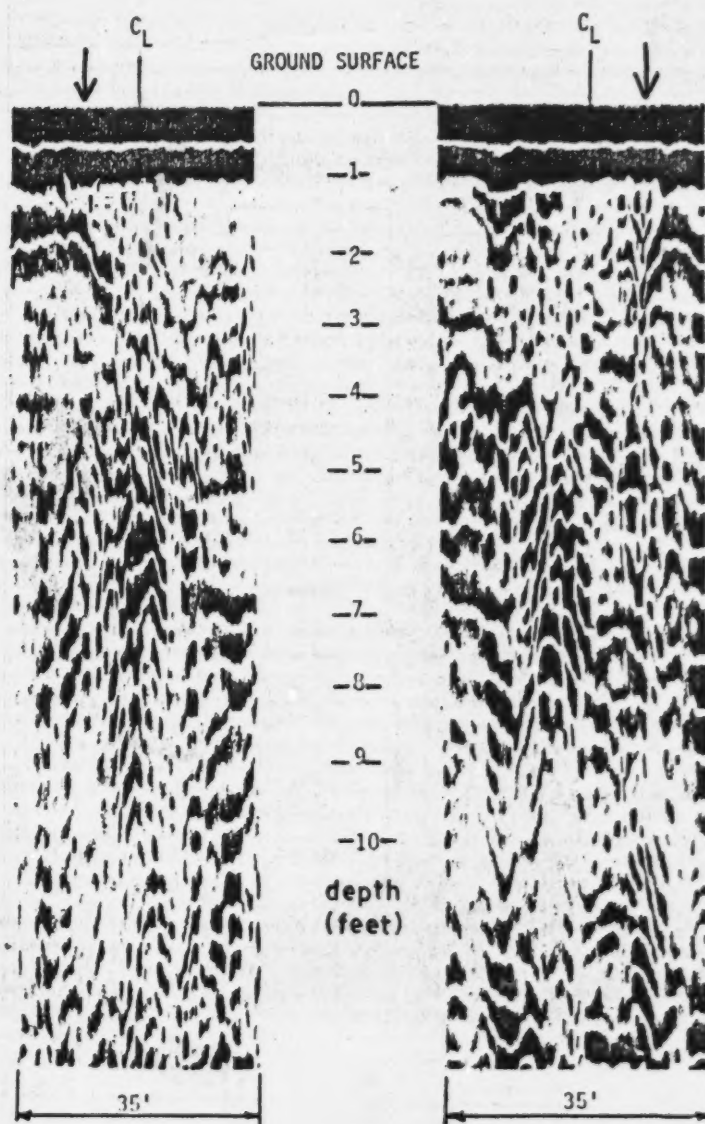


Figure 26 - Two GPR Scans Over a Metal "Trash Dump". Note the Downward Slopes at the Ends of Each Trace (at the Arrows), Indicating Sloping Side Walls of Filled-in Excavation.

Table 5.- Summary of Results from all Other Patterns (at "Best Possible" Site)

Method		Seismic	Resistivity	GPR	CW- μ Wave	MD	EMI	MAG
STEEL DRUMS								
(EMPTY)								
Various Depths (30 gal.)	X	X	detected all	X	detected all but 10' deep	detected all but 10' deep	detected all	detected all
Various Sizes (55, 30, 5; 2- 3.5' cover)	X	X	detected all	X	detected all	detected all	detected all	detected all
Various Orientations (in 3' cover)	X	X	only good perpendicu- lar to axis of drum	X	detected all	detected all	detected all	detected all
PLASTIC DRUMS								
Various Depths (40 gal. empty)	X	X	only at 1'	X	X	only at 1'	X	X
Various Contents (2' cover) Salt Water	X	X	much bet- ter than empty	X	X	X	X	X
(2' cover) Fresh Water)	X	X	much bet- ter than empty	X	X	X	X	X
TRASH DUMP	X	X	locates excavation boundaries	X	detected well	detected well	detected well	detected well

Note: "X" suggests that the method used is of little or no value in this particular situation.

Table 6,- Summary of Results of Various NDT Methods (at "Best Possible" Site)
(ST is steel; Pl is plastic)

METHOD	GPR		Metal Detector	EMI		Magnetometer
CAPABILITY	ST	Pl	ST	ST	Pl	ST
Depth Detection	to 10'	to 3'	to 10'	to 6'	to 1'	to 10'
Axial Resolu- tion	~10'	~10'	~4'	~10'		~10'
Lateral Scan Sen- sitivity	Poor	Poor	Good	Excellent		Excellent
Soil Condition Sensitivity	Very	Very	Good	Good		Insensitive
Sensitivity to Orienta- tion to Drum	Very	Very	Good	Good		Good
Size of Drum Sen- sitivity	Moderate	Moderate	Fair	Fair		Good
Sensi- tivity to Contents of Drum	None	Liquid filled best	None	Very little		Very little
Ease of Deployment	Moderate		Very Easy	Easy		Very Easy
Data Inter- pretation	Moderate		Very Easy	Easy		Easy
Expense of Equipment	~\$40,000 (with recorder)		\$300-500	~\$8000		\$3000-5000
Major Draw- backs	Cost		Does not work on plastic	High cost Very limited on plastic		Only works on magnetic materials
Major Advantages	Need not be metal- Determines depth		Sensitive and very low cost	Very sensitive		Very sensi- tive - Not sensitive to background conductivity

6.2.1 Description of Experimental Methods

Since the continuous-wave microwave technique was only marginally successful and seismic refraction and electrical resistivity techniques were not successful on the previously described best possible site, Lord, et al. (1982), they were not used for this more difficult situation. Commercially available metal detector (MD), electromagnetic induction (EMI), magnetometer (MAG) and ground probing radar (GPR) were used.

6.2.2 Site Details

The containers were buried in a heavy construction contractor's storage yard in North Wales, PA. The 250 ft by 120 ft area was bounded by trees and a drainage ditch to the north, a chain link fence to the east and south and miscellaneous forms, tanks and trailers to the west.

Disturbed and undisturbed samples indicated that the soil was a dense sandy silty clay of 128 lb/ft³ unit weight and 19% water content. This is equivalent to a 98% relative density (via standard Proctor compaction test) and 100% saturation. Other physical properties of the soil showed that the specific gravity was 2.54, the liquid limit was 32%, the plastic limit was 23% and the shrinkage limit was 11%. Regarding gradation characteristics, 21% was in the silt size range and 4% was the clay size range. Thus, the soil is classified as ML-CL by the United Soil Classification system. Being near the high point of the local topography, the soil was only about 4 ft to 6 ft thick above bedrock which was observed to be decomposed red shale, fractured at 4 ft but rapidly became sound at a depth of about 6 ft.

Eighteen steel and plastic containers were placed in backhoe-excavated holes that varied from 2 ft to 6 ft deep. The soil cover over the containers varied from 1 ft to 4 ft. The container burial patterns were as follows:

- Four 30 gal. steel containers buried with 1 ft, 2 ft, 3 ft and 4 ft of cover.
- Three steel containers (5 gal., 30 gal. and 55 gal.) buried at 3 ft of cover. (The 30 gal. drum was included in the previous pattern).
- Four 40 gal. plastic containers buried with 1 ft, 2 ft, 3 ft and 4 ft of cover.
- Four 30 gal. steel containers buried with 3 ft of cover. Three of the containers were adjacent to one another and the fourth was separated by 16 ft.
- Four 30 gal. steel containers with 1 ft of cover were each oriented at 90°, 60° and 0° with the horizontal.

In general, all containers were cylindrical, placed with their long axis horizontal (except where noted), placed empty, placed approximately 25 ft from each other (except where noted) and backfilled with the same soil that was excavated at the particular location involved. After hand backfilling and tamping soil around the drums, the site was further backfilled and compacted by a heavy dozer, graded off to a level condition and allowed to stabilize for approximately four months. During this time period the contractor brought

additional equipment onto the site which made the area more representative of conditions at an actual site. Figure 27 is a plan of the site, the containers and other relevant items.

6.2.3 Results

Each of the aforementioned NDT techniques were used at the site by making a series of seven parallel scans about 10 ft apart (see Fig. 27), with data being taken at 2-ft intervals along each scan. Results were transferred from profiles along each scan (results not shown due to space limitations), to generalized plan views. These generalized results are presented in this report.

The metal detector (commercially available from Fisher Company, Model M-Scope) gave results shown in Fig. 28. The cross hatched areas along scan lines show where the device gave a positive indication that each metal container was accurately located, but that none of the four plastic containers was located. Positive location of a buried object by the device is given by pinning of the dial indicator and by an audible signal. Positive signals were observed on scan lines where no containers were purposely buried. This is understandable since the site had numerous metal objects (old cans, reinforcing bars, fencing, springs, etc.) very near to the ground surface before the containers were buried. In the vicinity of the trailers and metal forms, the metal detector remained pinned continuously.

The results of the electromagnetic induction device (commercially available from Geonics Ltd., Model No. EM-31) are given in Fig. 29. Similar to the previous metal detector results, the system accurately located all metal containers, but no plastic ones (Fig. 29). The possible exception was the plastic container buried 1 ft deep along scan line #4. Anomalous spots were also seen along scan lines where no containers were buried but, as described before, quite possibly for the same reason. At a few of these locations the MD and EMI readings were in agreement, e.g., along scan line #5 at 90 ft west of the base line.

The magnetometer results (commercially available from EG and G Geo-Metrics, Model No. F-856) are shown in Fig. 30. The individual scan lines showing magnetic field data were interpreted and plotted for this figure. Correlation with actual container locations was very poor for the steel drums (which was unexpected) and for the plastic drums (which was expected). The westerly portion of each scan line became swamped due to the heavy magnetic metal (i.e., steel) concentration of the tanks, forms and trailers on the ground surface.

Results from the ground probing radar (commercially available from Geophysical Survey Systems, Inc., Model No. SIR-7) scans are not shown in the same format as the preceding techniques because results were very negative. A typical GPR trace along scan line #2 is shown in Fig. 31. The trace was made directly over the four 30-gal. steel drums buried at 1 ft, 4 ft, 2 ft and 3 ft, respectively, and then over the 55-gal. drum at a 3-ft depth. No discernible return signal was noted at the proper locations. This was typical of all GPR signals over the site.

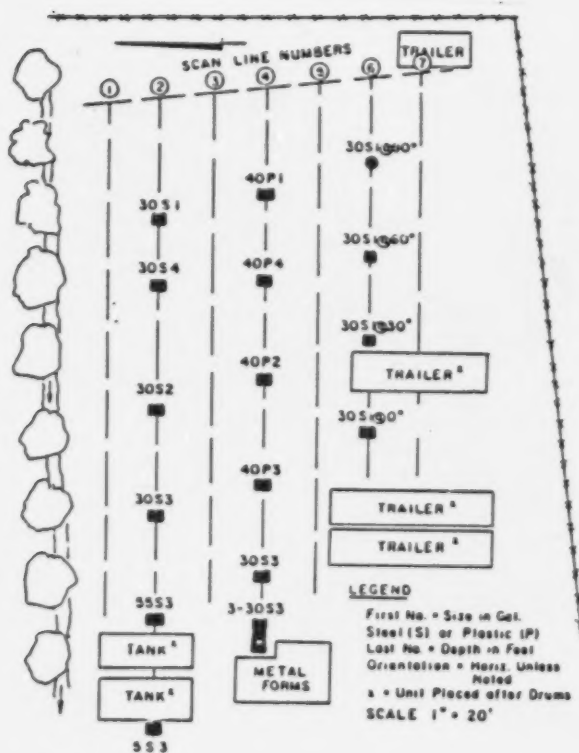


Figure 27 - Plan View of Site Boundaries and General Conditions, Buried Container Deployment and Survey Scan Lines for Various NDT Techniques.

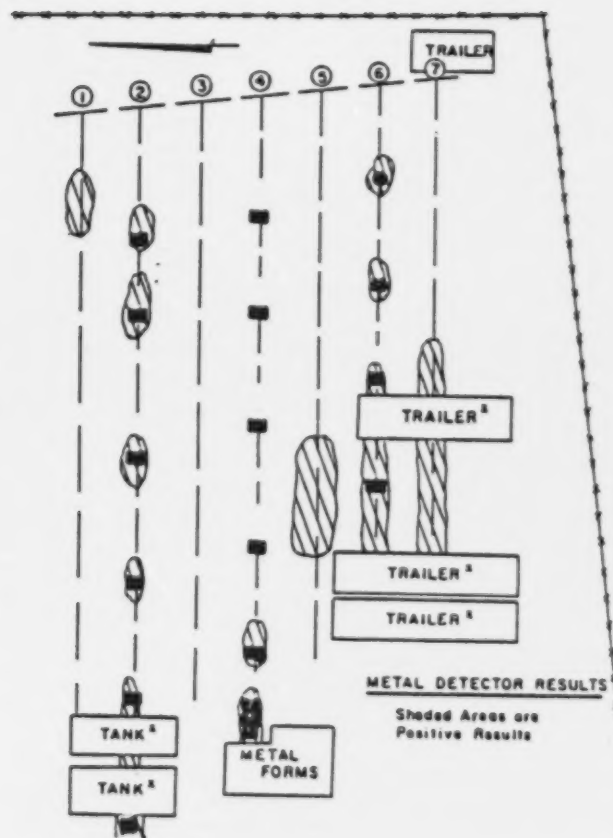


Figure 28 - Plan View of Site Showing Results of Metal Detector (MD) Survey.
See Figure 27 for Actual Container Identification.

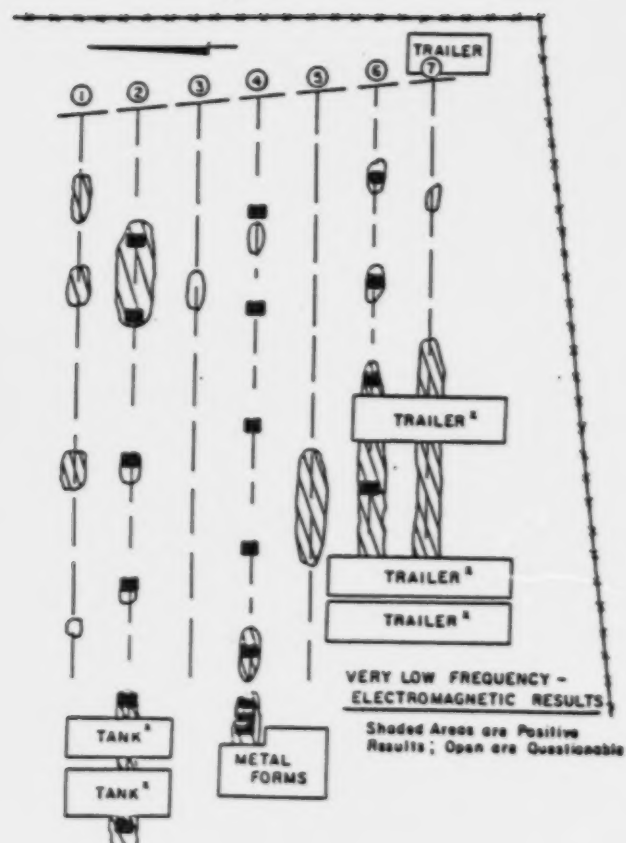


Figure 29 - Plan View of Site Showing Results of Electromagnetic (EMI) Survey. See Figure 27 for Actual Container Identification.

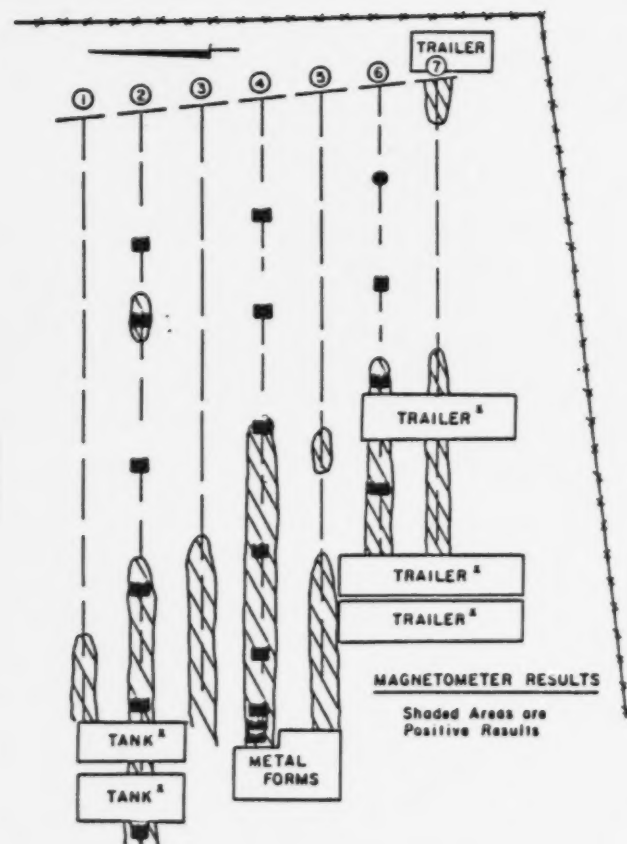


Figure 30 - Plan View of Site Showing Results of Magnetometer (MAG) Survey. See Figure 27 for Actual Container Identification.

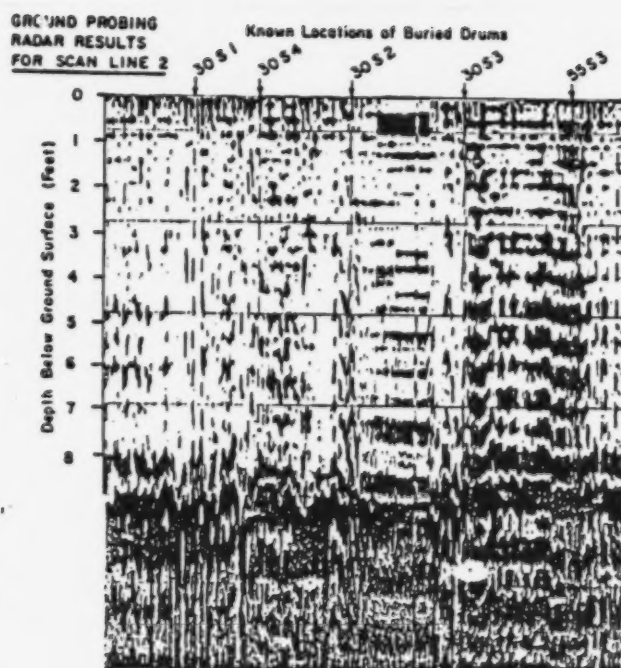


Figure 31 - Ground Probing Radar (GPR) Trace Over Scan Line #2 Showing Arrows Where Five Containers are Actually Located.

Four separate trips were made to the site, one before drum placement and three afterwards. Perhaps with more dry conditions a GPR system with signal enhancement capabilities would have shown the expected parabolic shapes indicating a curved object, but it was not obvious in this situation.

6.2.4 Discussion

In contrast to the earlier study of container detection in a dry sandy soil where most NDT techniques worked quite well, here there were definite problems. At this site conditions were much more formidable. The major difference between the sites were the:

- High clay content of the soil
- Complete saturation of the soil voids
- Closeness of the bedrock to the ground surface
- The fact that the bedrock surface was not abrupt but weathered from highly decomposed to very hard within a 2 ft thickness
- Relatively confined area where background noise is present.

In spite of the above difficulties, this is typical of many real sites having buried containers.

For this situation, the metal detector and electromagnetic induction methods worked equally well in locating metal containers. On the basis of equipment cost, the authors would favor the metal detector (\$500 versus \$8,000). The EMI has a deeper penetration depth and lateral scan sensitivity as determined from the earlier study. However, neither the MD nor the EMI will easily give the depth to the indication object.

The magnetometer was unsuccessful because of the abundance of buried metal (magnetic) objects. This conclusion was expected and confirmed by this work.

Somewhat surprising was the failure of the ground probing radar to detect even the shallow buried containers. Neither steel nor plastic could be located - a marked departure from the earlier study. Probably the saturated clay soil attenuated the signal before any significant penetration occurred or the background conditions submerged the signal in noise. GPR is the preferred technique known to the authors to give a specific depth to a reflecting object, but in this case was simply not successful.

Other NDT techniques that were marginally successful or unsuccessful at the sandy soil site were not deployed at this saturated clay soil site for the reasons stated earlier.

6.3 Evaluation of Four NDT Techniques with Containers Located Beneath Water Surfaces

Containers are also found at the bottom of waterbodies. Therefore, a study was undertaken to evaluate the four NDT methods with containers located on the bottom of waterbodies of various electrical conductivity. The waters varied from sea water (high conductivity) to fresh water (low conductivity)

[Lord, et al., (1984)].

6.3.1 Experimental Approach

The basic approach used in this study was to determine the capabilities of the four NDT techniques in locating submerged metal containers under water of different conductivities. The methods and approaches are similar to those described in the earlier works of the authors. Electrical conductivities of the water at each particular site were measured by an AC method to lessen electrode polarization effects. A schematic diagram of the "home-made" electrical conductivity apparatus is shown in Fig. 32. The method gave quite accurate results when compared to literature values on comparable sea water.

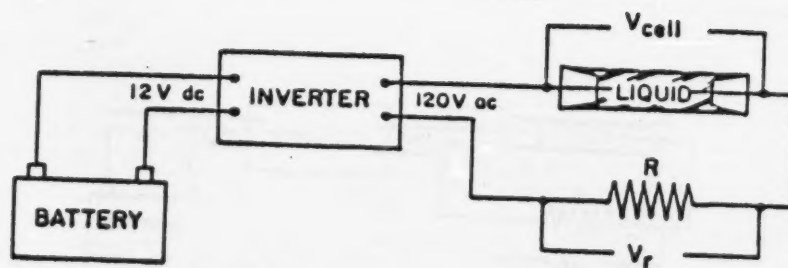
The locations of the field sites were a fresh water creek in the Pine Barrens of New Jersey (Site 1), along the Delaware River in Pennsylvania (Site 2) and Delaware (Site 3), and in sea water at Barnegat Light, NJ (Site 4). The sites and the electrical conductivities of the water at each site are listed in Table 7.

6.3.2 Results

The results are presented on a technique-by-technique basis and not on a site-by-site basis. This gives a clear distinction of each technique's capability as a function of the water's electrical conductivity.

TABLE 7. - LOCATIONS OF WATER FIELD SITES, TYPES OF WATER AND SOIL BOTTOMS, AND ELECTRICAL CONDUCTIVITIES OF THE WATER

Location of Site	Type of Water	Type of Bottom	Electrical Conductivity of Water (mho/m)
1. NJ Pine Barrens	A cedar creek	sand	0.04
2. Eddystone, PA	The Delaware River 60 miles upstream from Atlantic Ocean	soft river silt and clays	0.04
3. Delaware City, DE	The Delaware River 30 miles upstream from Atlantic Ocean	very soft river silt and clays	0.6
4. Barnegat Light, NJ	Atlantic Ocean Sea Water	sand	4



where

$$\sigma = (\text{G. F.}) \frac{V_{\text{cell}}}{V_r} (R)$$

G. F. = Geometric Cell Factor

Figure 32 - Schematic Diagram of the ac Electrical Resistivity Measurement Apparatus for Detection of Water Salinity.

Metal Detector -- The metal detector was useful only at the fresh water creek in the New Jersey Pine Barrens (Site 1 - Table 7). The results of a scan taken over a single submerged 55-gal. steel drum with 28 in. of water cover are shown in Fig. 33. A scan over two submerged 5-gal. steel drums (with about 30 in. of water cover) did not reveal the drums.

The metal detector proved to be of no value at the other three sites, for the instrument could not be "zeroed" due to the highly conductive electrical background present. This is understandable in terms of the high conductivity of the water at sites 3 and 4. Sites 1 and 2 had the same water conductivities; however, there may have been some scrap metal on the bottom of Site 2 since it is a highly frequented area (bottom debris consisted of broken concrete, reinforcement bars, miscellaneous cans, etc.).

Electromagnetic Induction -- A composite drawing of the EMI results at the four sites is shown in Fig. 34. In each case, three 5-gal. steel drums and one 55 gal. steel drum were used in the spatial distribution shown. The water cover for each drum is indicated on the figure. Since the smaller drums submerged in the creek at Site 1 had a tendency to move downstream in the river current, their position is not completely specified by the assumed initial distribution.

In fresh water (Sites 1 and 2) the 55-gal. drum was easily detected in 2 ft of water. The 5-gal. drums are detectable under 3 ft of water, but the interpretation of the scan is not completely straightforward.

In the more conductive waters (Sites 3 and 4), the 5-gal. drums were essentially "invisible" to the EMI technique at any depth, while the 55-gal. drum was still detectable. However, the higher background (refer to ordinates of the figures) makes detection of even the larger drum more difficult.

Magnetometer -- The magnetometer data are presented in Fig. 35. The main variables affecting the results here are the distance of the drum from the surface and the size of the drum. The only drums that were not detected with the MAG technique were the small ones with the most water cover, e.g., the 5 gal. drums at Site 2 with 3 ft. of water cover.

Ground Probing Radar -- In this case, the techniques should be called WPR, water penetrating radar. However, GPR has been accepted as the general abbreviation for the technique regardless of where used. This method only works in fresh water. The high wave attenuation associated with the electrical conductivity of sea water precludes its use. This study also found that reducing the electrical conductivity by a factor of ten from sea water (refer to Table 7) does not help in this regard. A GPR scan at Site 3 is shown in Fig. 36. The 55-gal. steel drum under only 1 ft of water is completely "invisible" to the technique.

Contrasted to the previous behavior are the results from Site 2 (Fig. 37). In this case, the 55-gal. drum under about 2 ft of water is clearly detected and delineated; the three 5 - gal. drums are also "seen" (quite separately) very well by the GPR technique at a water cover of about 3 ft. The GPR results at Site 1 were essentially the same as those presented for

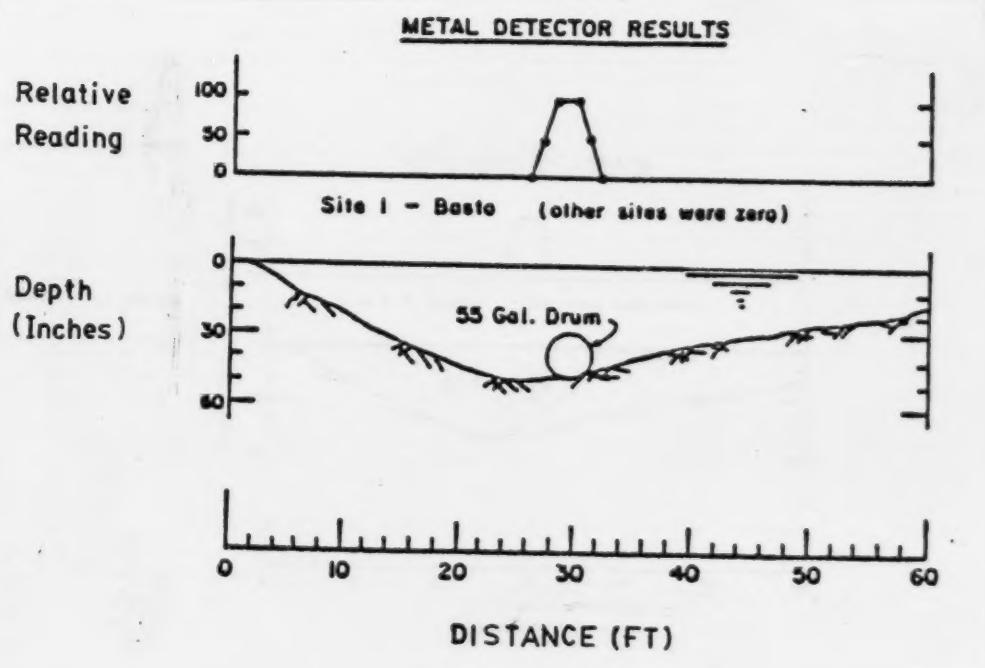


Figure 33 - The Metal Detector (MD) Scan for Water Site 1.

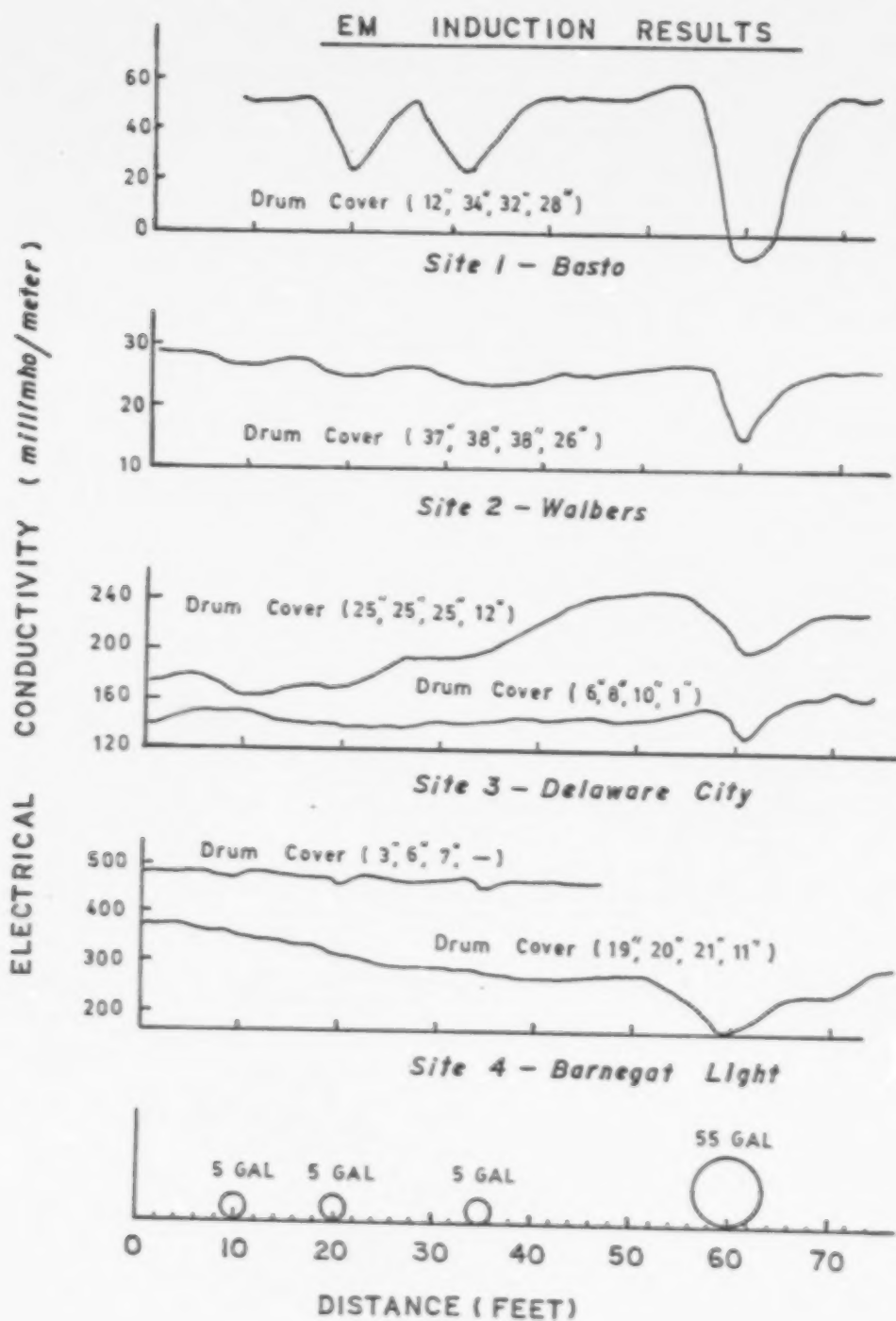


Figure 34 - The Electromagnetic Induction (EMI) Scans Over the Four Water Sites. The Spatial Distribution and Water Cover for the Drums are Indicated on the Figure.

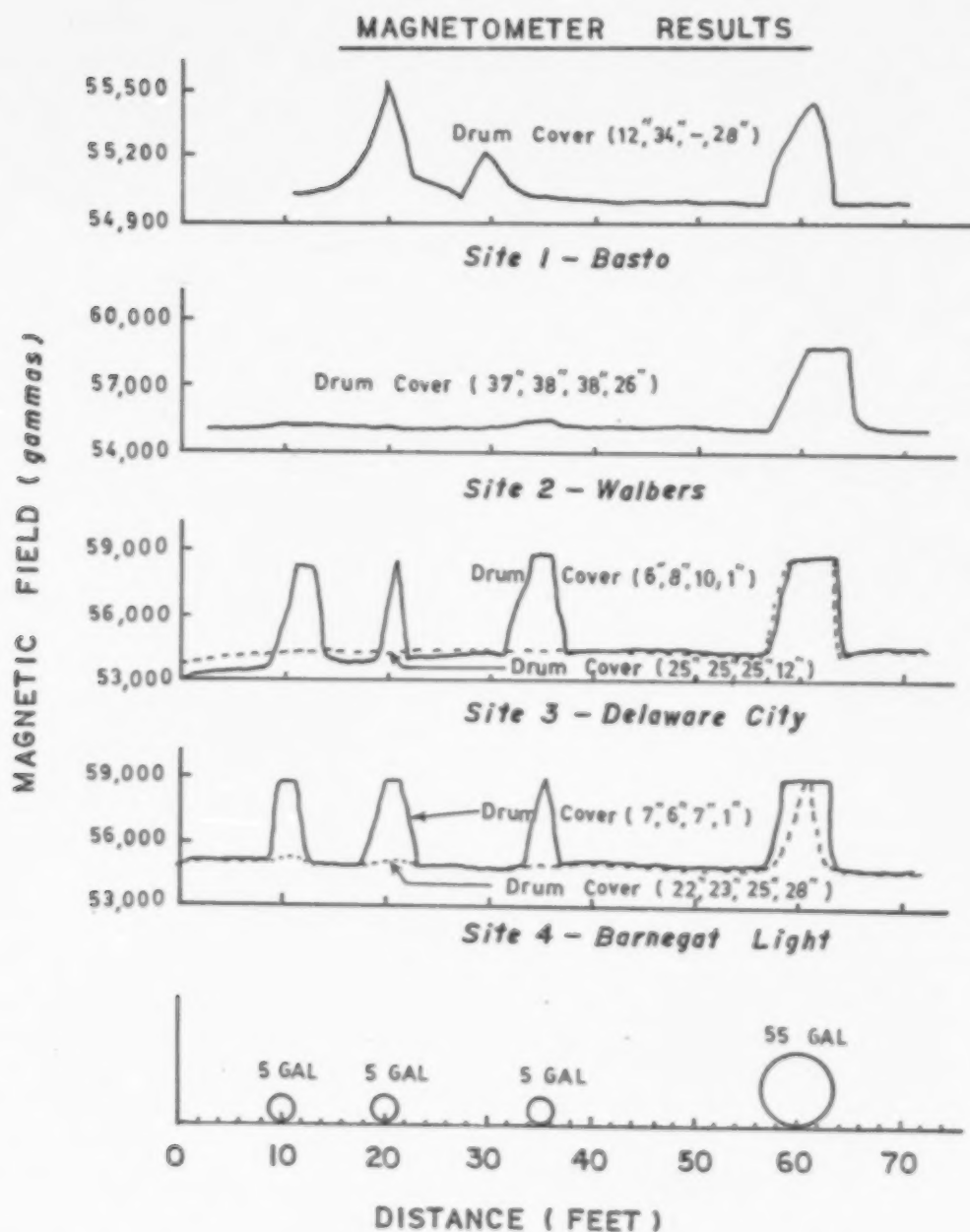
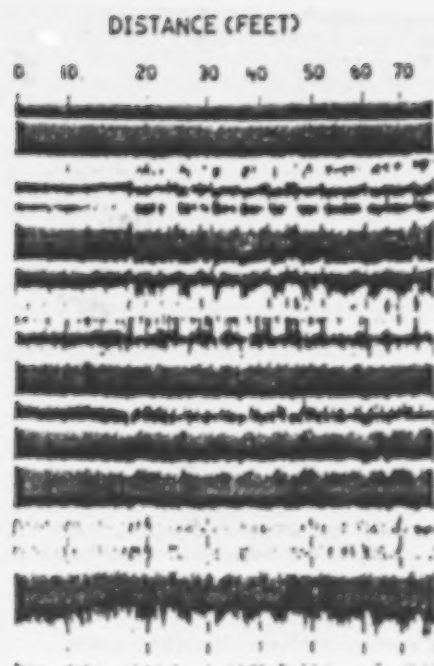


Figure 35 - The Magnetometer (MAG) Scans from the Four Water Sites. The Spatial Distribution and Water Covers for the Drums are Indicated on the Figure.



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Figure 36 - Ground Penetrating (GPR) Scan at Water Site 3. The Antenna Passed Directly Over a 55-gallon Steel Drum (with one foot of water cover) at the 60 Foot Mark.

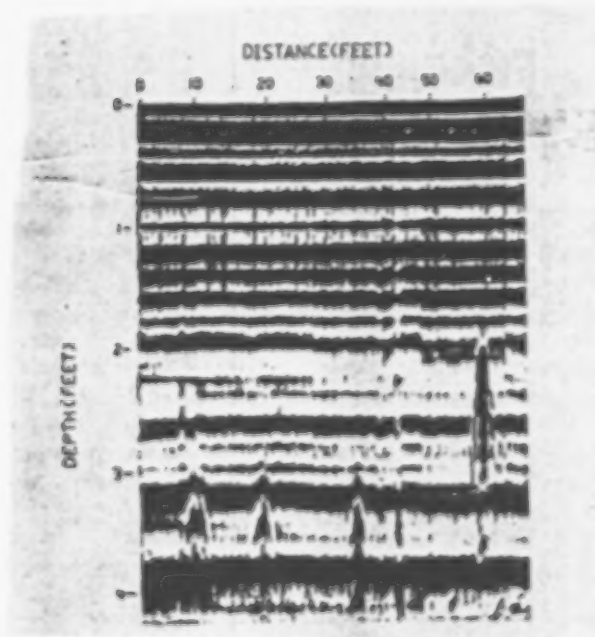


Figure 37 - Ground Penetrating Radar (GPR) Scan at Water Site 2. Clearly Seen are the 55-gallon Steel Drum (with 2 feet of water cover) at 60 Feet, and the Three 5-gallon Steel Drums (with 3 feet of water cover) at 10, 20 and 35 feet. The Level Bottom is Also Seen at About 3-3/4 Feet Depth.

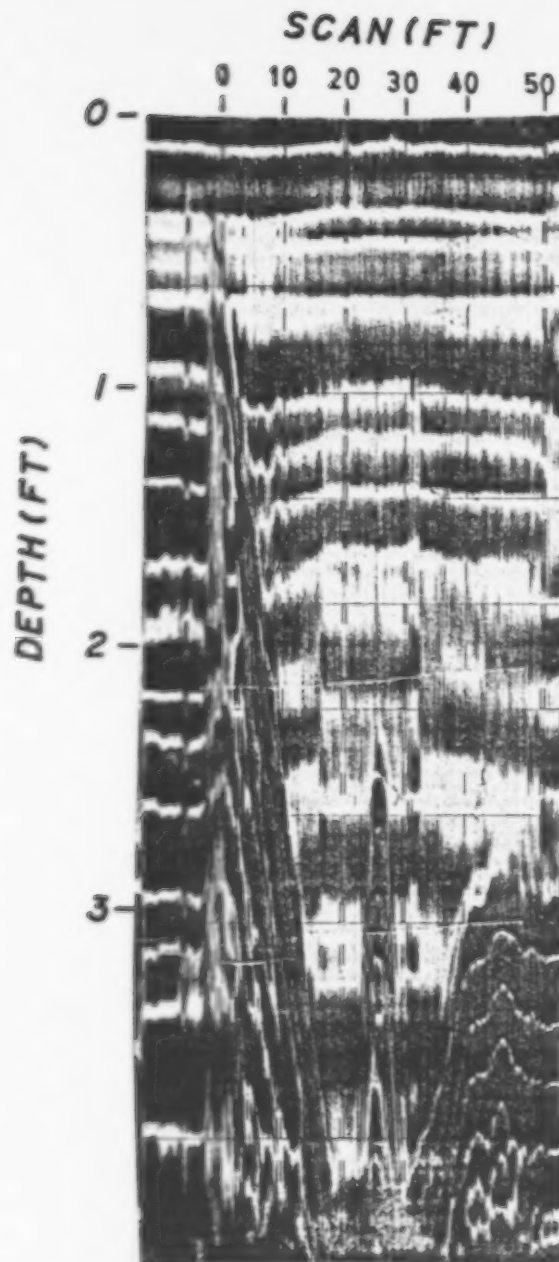


Figure 38 - Ground Penetrating Radar (GPR) Scan at Water Site 1. Clearly Seen is the 55 Gallon Drum at the 25 Foot Location (with about 2-1/2 feet of water cover). Also Seen is the River Bottom From 0 Feet at the Left Hand Side to About 3 Feet Depth at the Right Hand Side.

Site 2. All 5-gal. drums and the 55-gal. drum were clearly located. The scan over a single 55-gal. drums at Site 1 is shown in Fig. 38.

6.3.3 Discussion

Certainly all questions regarding the use of NDT techniques in under water container detection have not been addressed by the present study. However, it is felt that the following statements can be made:

- The metal detector is potentially useful in purely fresh water. The fresh water site, however, must be free of disturbing metallic influences. Once the background water conductivity reaches about 0.1 mhos/m, the MD is quite useless.
- The inductance method (actually a form of geophysical resistivity measurement) is useful in all water conductivities. However, its resolving power drops off somewhat at the higher conductivities (approximately 0.1 mho/m).
- The magnetometer is affected very little by electrical conductivity; only magnetic objects interfered with it. For example, an aluminum drum could not be located using the magnetometer.
- The ground penetrating radar is useful only in water which is essentially fresh. Any significant increase in electrical conductivity from that of fresh water results in a strong attenuation of the signal and, hence, a lack of propagation of the signal.

6.4 Evaluation of the Four NDT Techniques in a Saline Sandy Soil

The NDT techniques were further evaluated at a site with salt-water contaminated sandy soil [Koerner and Lord, (1984)].

6.4.1 Details of this Study

The site selected for this study was on an island in a bay at the southern New Jersey shore. Within a distance of approximately 150 ft from the water's edge, the ground surface rose to 10 ft above sea level where it became relatively level in elevation. The soil was a medium to fine, granular, sand indigenous to that area of southern New Jersey. The sand density ranged from loose (near the surface) to intermediate at a depth of 6 ft, the limit to which we could excavate.

All containers were made of steel and varied in size from 1 to 55 gal. They were placed in hand excavated holes and backfilled to approximately the same density as the adjacent undisturbed soil. The containers were empty and clean.

Four separate test patterns were deployed, each with a specific objective:

- In a low conductivity area, to determine if the results would be similar to the "best possible" site results and if each method was working properly. In this regard, two patterns were used; one employed five 30-gal. containers each 25 ft apart at 9, 18, 25, 32 and

50 in. cover respectively; the other used containers with a constant cover of 32 in. (also 25 ft apart) but in sizes ranging from 1, 5, 20, 30 to 55 gal, respectively.

- In a varying conductivity area extending inland from the ocean front. Here the containers were buried under either 18 or 24 in. of cover (at varying distances apart) and varied in size from 1 to 30 gal.
- In a high conductivity area to attempt to determine the limits of a "trash dump" measuring 9.3 ft x 4.2 ft containing a large amount of miscellaneous metal items (barrels, tables, rods, steel sections, etc.).

Each test pattern was monitored using the four NDT methods described earlier.

6.4.2 Results

The results obtained with the five different sized containers (55, 30, 20, 5 and 1 gal.) under a constant soil cover of 32 in. are shown in Fig. 39. On the conductivity plot obtained from the EMI method, it can be seen that the background area is about 15 millimho/m which is similar to that at the "best possible site." Only the two largest size containers can be detected. Plotted beneath this response are the MAG and MD response curves, both of which clearly detected all containers except the 1 gal. The GPR trace of Fig. 40 gives a similar response.

The response curves showing the effect of varying soil cover over equal size 30 gal. containers are given in Fig. 41. Here the EMI and MD methods are seen to be sensitive to about 36 in. depth, while the MAG method easily detects all containers, even the one buried at 50 in. depth. The GPR trace of Fig. 42 accurately indicates containers buried at all depths.

In Fig. 43, a series of six containers (1, 5, 30, 30, 30, 30 gal.) were buried at varying distances from the ocean itself. The attempt was to keep all cover depths at 24 in., but the one closest to the ocean constantly flooded out, so 18 in. was used in this case. The EMI plot shows the conductivity exponentially decreasing from 240 millimho/m at the ocean's edge to background conditions 150 ft inland. No containers were located on a plot of this scale; however, the most inland 30 gal. containers were detected on a plot with a scale the same as Figure 41. The MAG response was not defined until the container at 32 ft was encountered. Further inland it performed well. The MD was pinned near the ocean front and it became unpinned only after we were 36 ft inland where it performed well from that point onward. The GPR trace of this scan (not shown) only picked up the 30 gal. container at the 149-ft location. Lastly, the "trash dump" of Figure 44 was monitored. Here the EMI response shows a high background conductivity at the site of 30 to 40 millimho/m, but the heavy metal concentration is easily noted. Also easily noted were the boundaries using the MAG, MD and GPR (not shown) methods. While each of the method indicated the "trash dump" boundaries, none revealed any detail of items within the "trash dump" itself.

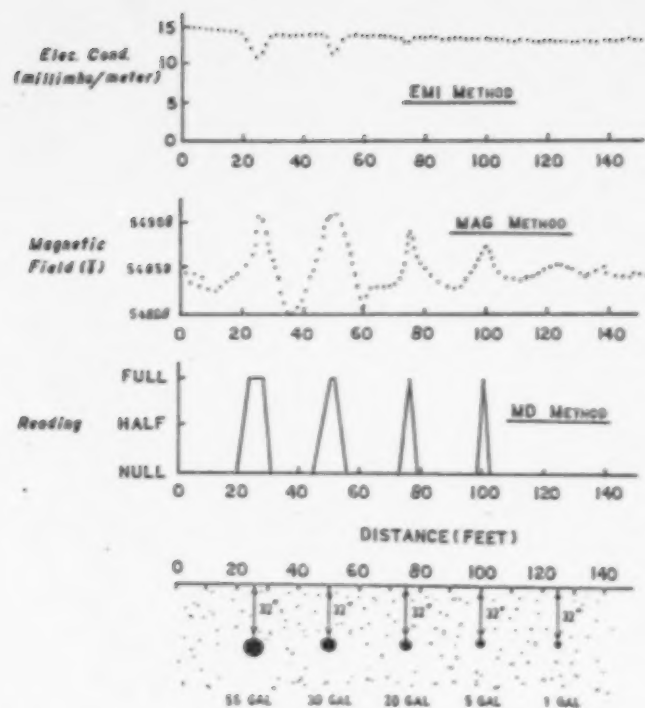


Figure 39 - Results of EMI, MAG and MD on Varying Size Steel Containers Buried at 32 inches of Cover.

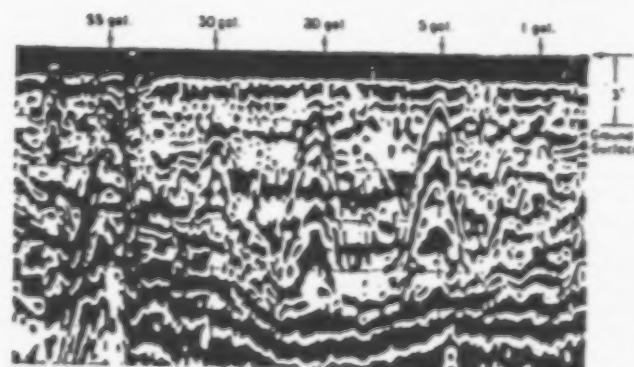


Figure 40 - Results of GPR on Varying Sized Steel Containers Buried at 32 inches of Cover.

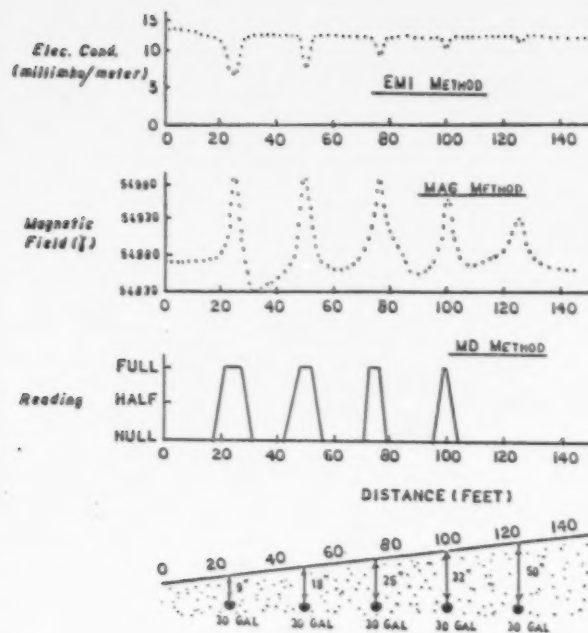


Figure 41 - Results of EMI, MAG and MD on 30-gallon Steel Containers Buried at Depths Varying from 9 inches to 50 inches.

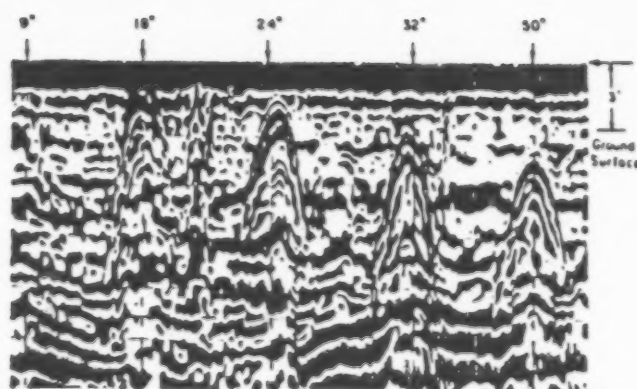


Figure 42 - Results of GPR on 30-gallon Steel Containers Buried at Depths Varying from 9 inches to 50 inches.

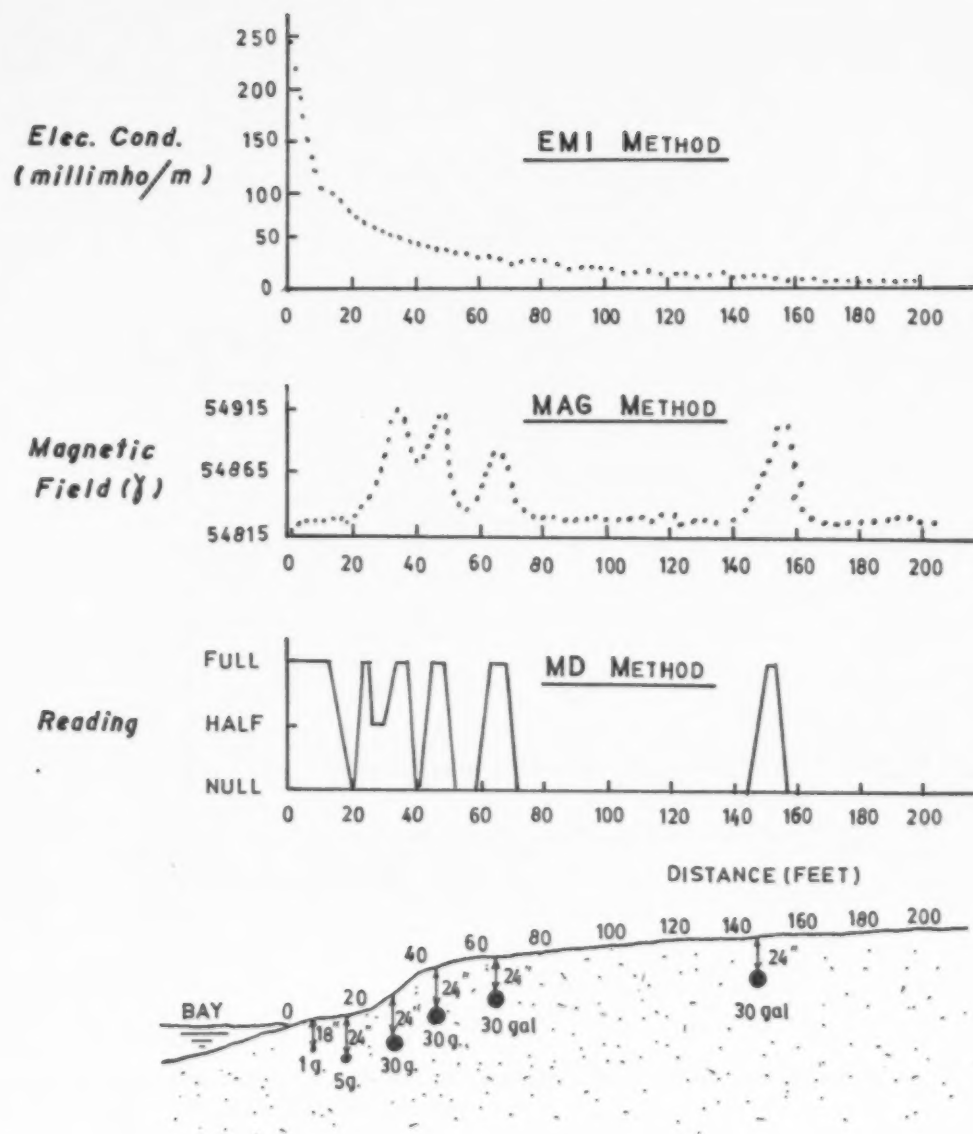


Figure 43 - Results of EMI, MAG and MD on Buried Containers as a Function of Varying Soil Conductivity.

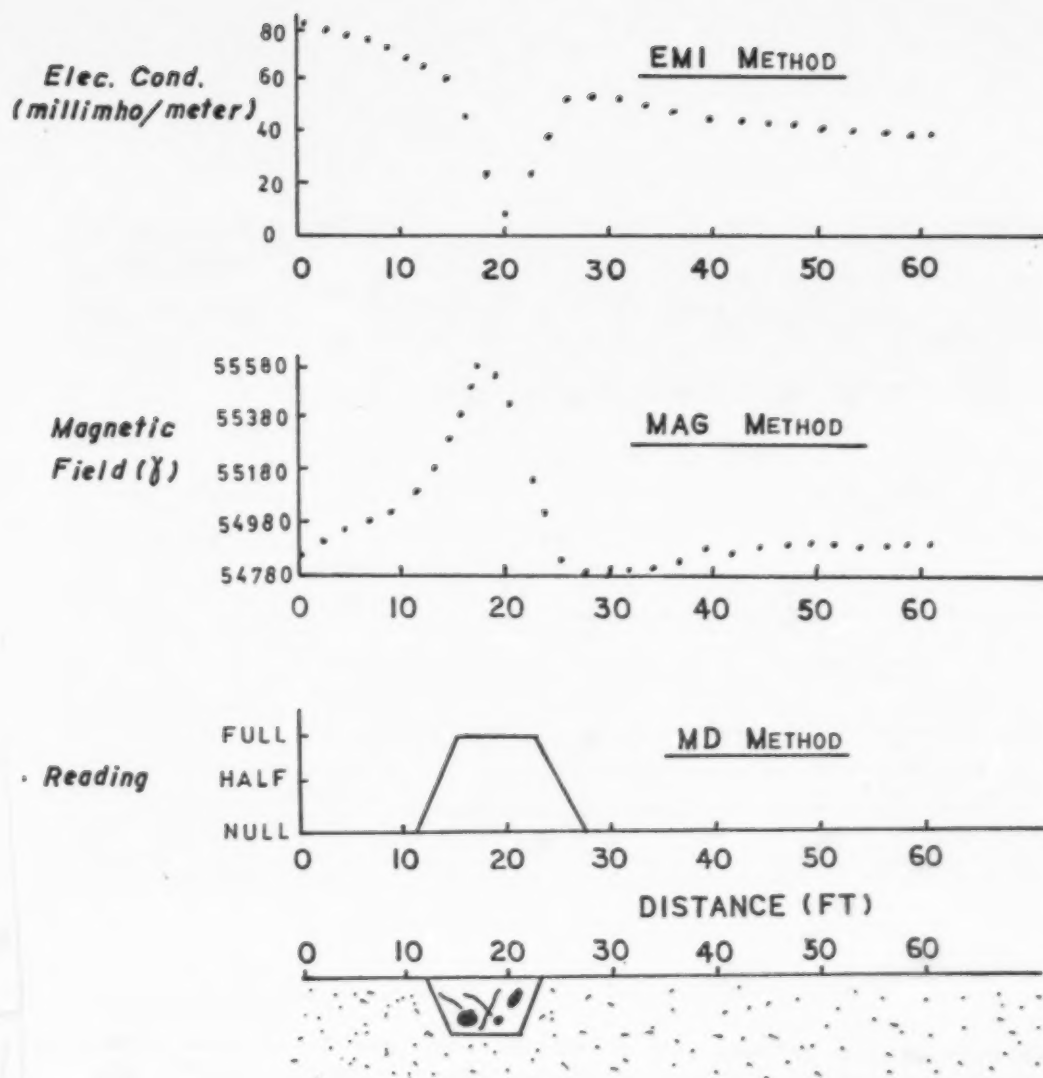


Figure 44 - Results of EMI, MAG and MD in Delineating the Boundaries of a "Trash Dump." Scans are Taken Directly Over the Centerline of the "Trash Dump."

6.4.3 Discussion

The tests of the NDT devices in sandy saline soils showed that: (a) For location of individual buried containers, conductivity greater than 20 millimho/m seriously impairs use of the electromagnetic based systems, i.e., MD, EMI, and GPR; (b) The boundaries of a "trash dump," however, were delineated by all of the methods; and (c) At conductivities less than 20 millimho/m, the four NDT methods performed well and similar to the "best possible site" which was also in a granular soil but not in an ocean environment.

6.5 Evaluation of Four NDT Techniques at a Sandy Soil Site with Buried Plastic Containers

Most all of the work previously described in this report dealt with buried metal objects. Many chemicals are also stored and discarded in plastic containers. For this reason, a study was undertaken to determine the capabilities of the NDT methods in detecting plastic drums [Lord and Koerner (1986a)].

6.5.1 Details of this Study

The location of this experimental test site is on an island in an ocean bay in southern New Jersey. Work proceeded away from the shoreline where the electrical conductivity was generally less than 10 millimhos/meter. The soil was a medium to fine, angular sand indigenous to that area. The sand density ranged from loose (near the surface) to intermediate at a depth of 6 feet, the depth to which we could manually excavate.

All containers were made of plastic and were either of 5-gal. or 35-gal. capacity. They were placed in hand-excavated holes and backfilled to approximately the same density as the adjacent undisturbed soil. A major goal of this study was to ascertain the effect of varying electrical conductivity of the container contents. Therefore, the drums were filled with either air, fresh water, or salt water. The test patterns used were:

- Burial of six 35-gal. containers 25 ft apart, all at 26 in. of soil cover. The contents were respectively 100 percent air, 50 percent salt water/50 percent air, 100 percent salt water, 100 percent fresh water, 50 percent fresh water/50 percent air, and 100 percent air.
- Burial of five 5-gal. containers with various soil covers (6, 12, 34, 36 and 48 in. and 25 ft apart. Separate surveys were made with each container having either: 100 percent air, or 100 percent fresh water, or 100 percent sea water.

Each test (burial) pattern was evaluated using the four NDT methods described earlier.

6.5.2 Results of this Study

Figure 45 shows the results of the EM and MAG surveys as they were traversed over six 35-gal. containers having a constant soil cover of 26 in. There are no pronounced indications of the buried containers in either the EMI or MAG scans. That is, there are no abrupt discontinuities in the plots as for example can be seen in Figures 39 and 41. Also (but not shown) there was no indication of the containers being present using the MD.

Figure 46 shows a GPR scan over this same distribution of containers. All containers are clearly visible, with the empty ones being the least discernible and the salt water ones being the most discernible. (If no containers were present, the lines in the scan would be more nearly horizontal, refer to Figure 1.) The dark background sloping downward from left to right is the (salt) water table. This agrees with the scan topography: the scan (parallel to the shore line) is going uphill from left to right. This fact also accounts for the decrease in background conductivity in the EMI results (Figure 45) when moving from left to right (uphill). That is, less of the high conductivity salt water is being surveyed as one moves uphill and increases the distance to the elevation of the water table.

Figure 47 shows the results for the EMI and MAG surveys over the 5-gal. plastic containers buried at various depths. The results are quite similar for air, fresh, and salt water, so they are all superimposed on one set of curves. No definite indication of any container is present. The variation of MAG results seems to be somewhat random, for a second scan over the same area in each of the three fill cases indicated that this same random variation of $\pm 20\gamma$ was present in all scans.

The MD results also gave no indication of the buried containers under any circumstances and are not shown for this reason.

Figure 48 shows the GPR scan over the empty 5-gal. containers. There are only faint indications of the containers here. Figure 49 gives the results for the fresh water filled containers. The containers at 24, 36, and 48 in. are somewhat discernible, the shallower ones probably being somewhat obliterated by the large transmission pulse (the black lines on top of the scan). Figure 50 shows the results with the containers filled with salt water. All drums are now discernible. Note that the water table is clearly detectable in Figures 48, 49 and 50. Also, note from the GPR surveys that the water table is much closer to the surface at the start of the scan than it was in Figure 46. This is probably the reason that the EMI results start off at a higher value (50 millimhos/meter) than in Figure 45 (20 millimhos/meter).

6.5.3 Discussion

Specifically, it was found that:

- 35-gal plastic drums under moderate soil cover (~26 in.) cannot be located with EMI, MAG, or MD, irrespective of the electrical conductivity of the contents of the containers. Thus, a 35-gal. container filled with salt water (of conductivity ~500

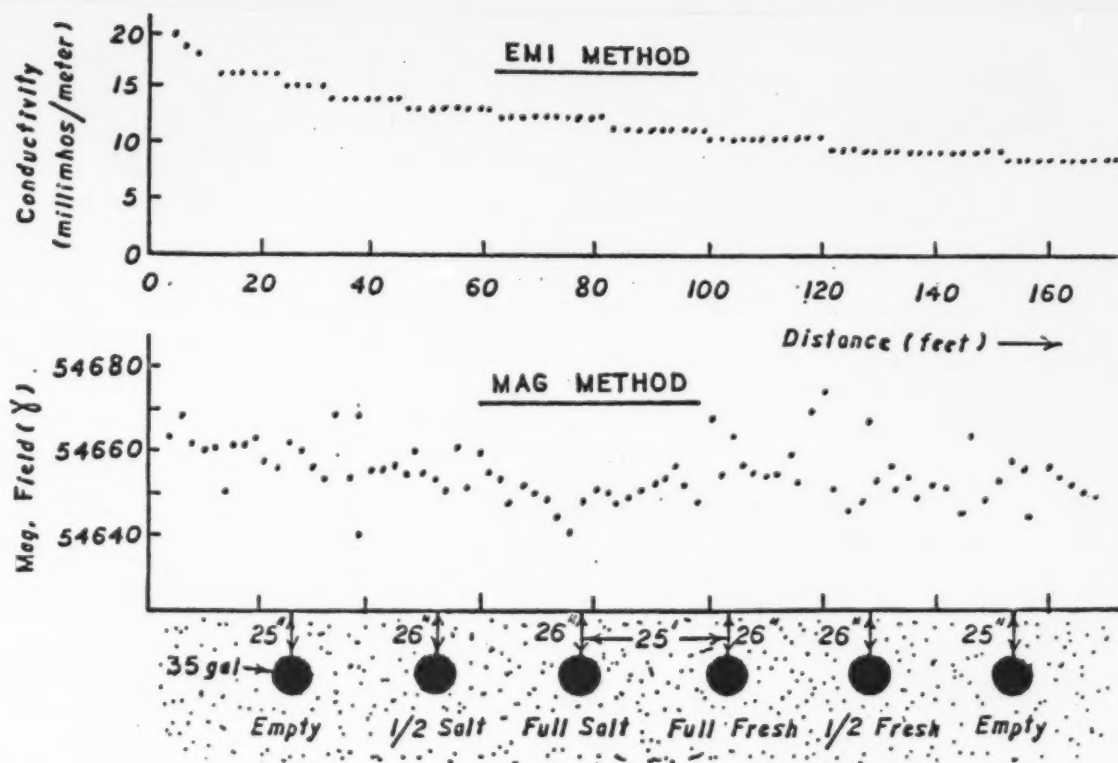


Figure 45 - Electromagnetic Induction (EMI) and Magnetometer (MAG) Surveys Over 35-gallon Plastic Containers Buried Under 26 inches of Sand Cover, 25 feet Apart. Results Apply for Container Contents of Air, Fresh Water and Salt Water.

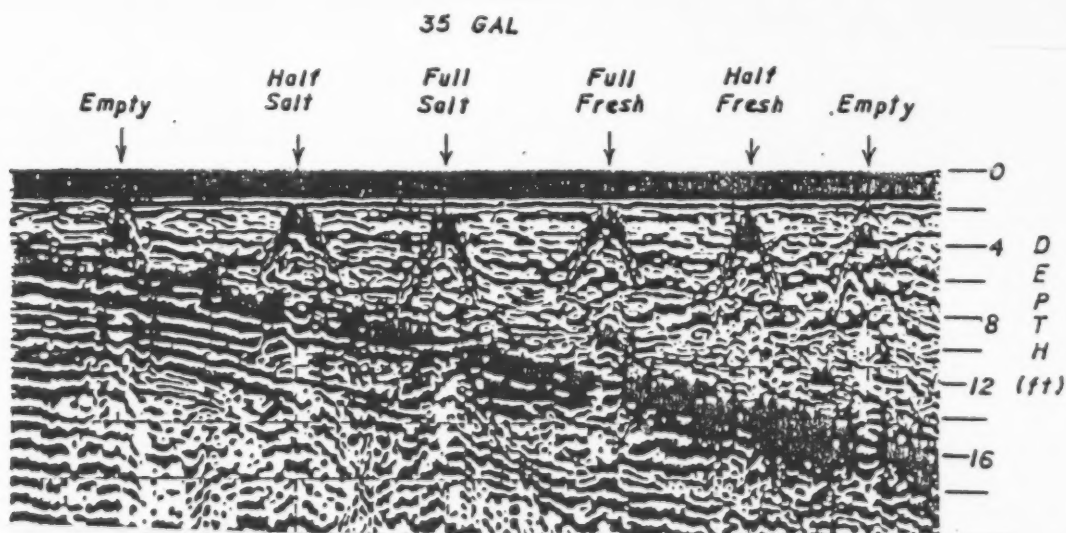


Figure 46 - Ground Penetrating Radar (GPR) Scan Over 35-gallon Plastic Containers Buried Under 26 inches of Sand Cover and Placed 25 feet Apart. Results Apply for Container Contents of Air, Fresh Water and Salt Water as Indicated.

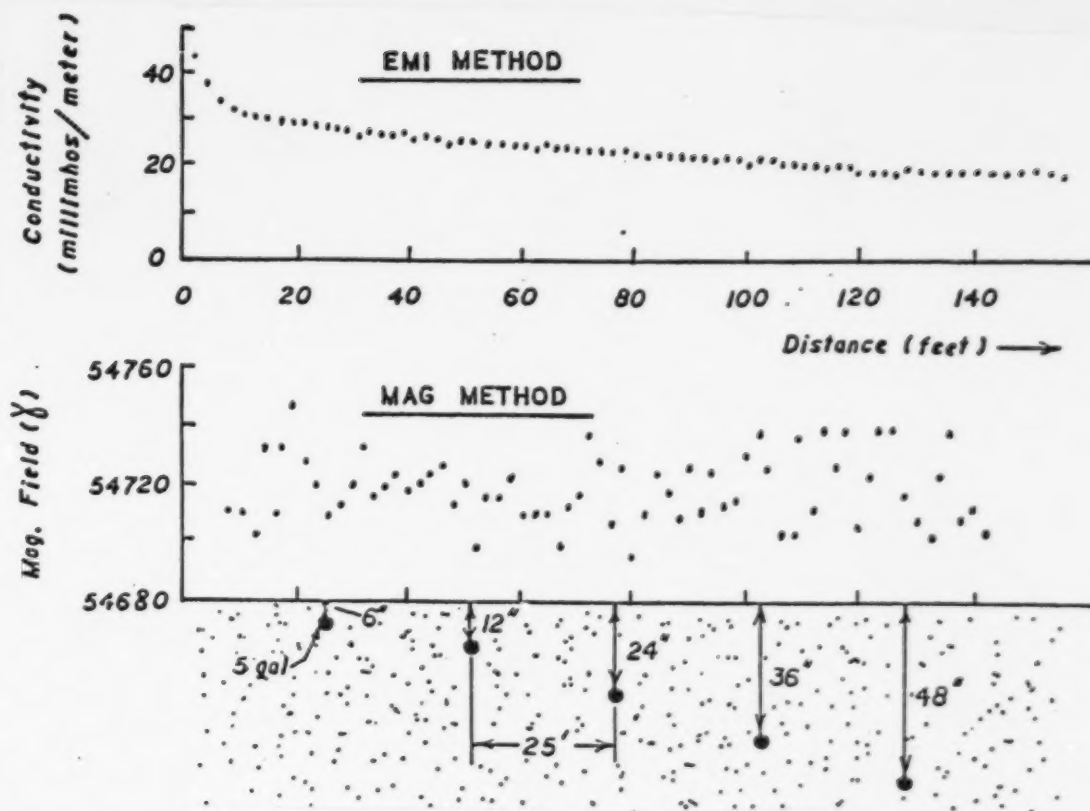


Figure 47 - Electromagnetic Induction (EMI) and Magnetometer (MAG) Surveys Over 5-gallon Plastic Containers Buried Under Various Sand Covers (6 to 48 inches) and Placed 25 feet Apart. Curves Apply Equally Well for Container Contents of Air, Fresh Water and Salt Water.

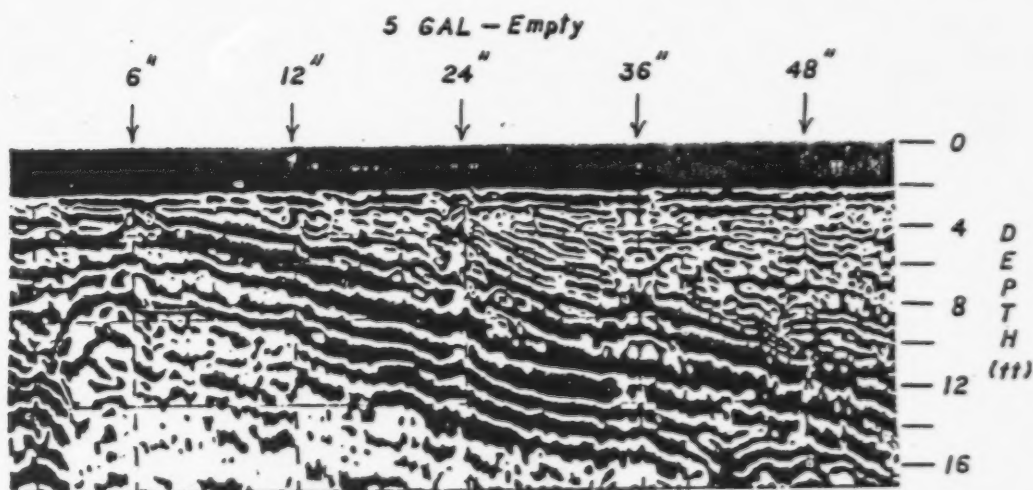


Figure 48 - Ground Penetrating Radar (GPR) Scan Over Empty 5-gallon Plastic Containers Buried in Sand Covers in the Depths Shown on Top of Figure.

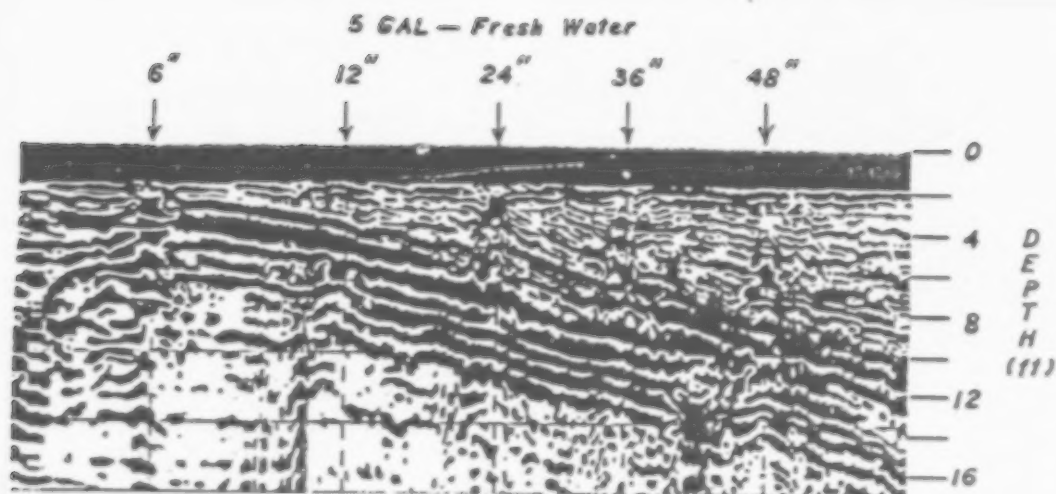


Figure 49 - Ground Penetrating Radar (GPR) Scan Over Fresh Water-Filled 5-gallon Plastic Containers Buried in Sand Covers at the Depths Shown on Top of Figure.

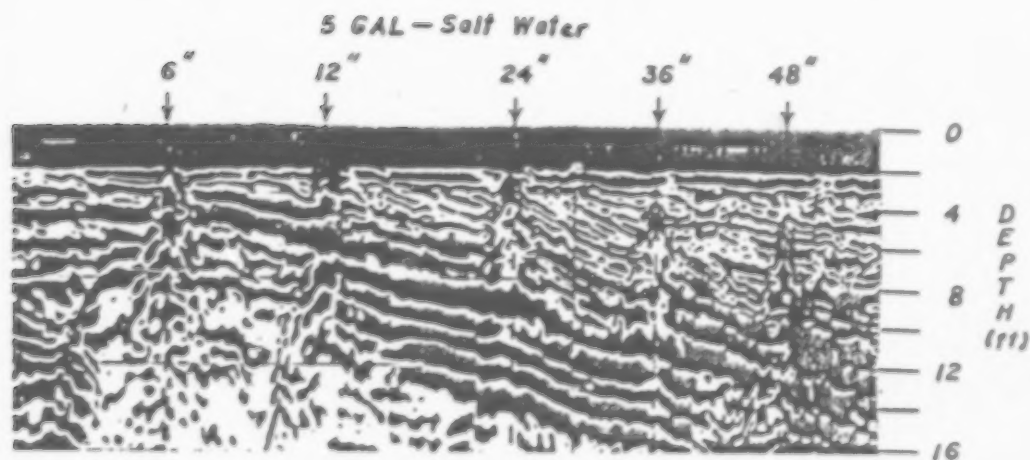


Figure 50 - Ground Penetrating Radar (GPR) Scan Over Salt Water-Filled 5-gallon Plastic Containers Buried in Sand Covers at the Depths Shown on Top of Figure.

millimhos/meter) does not offer enough contrast in conductivity to be detected.

- GPR can discern 35-gal. plastic containers under moderate soil cover. Empty drums can be discerned, but if the drum contains water, especially salt water, it is much easier to discern. This is an important finding, for the contents of actual drums in the field can vary over a large range of conductivity. (For example, acidic or basic waste can have relatively high conductivity, whereas many organics have very low conductivity.)
- 35-gal. plastic containers cannot be detected with EMI, MAG, or MD under any amount of soil cover (6 to 48 in.). This result applies whether the containers are filled with air, fresh water, or salt water.
- GPR can be used to detect 5-gal. plastic containers buried in sand. Air filled containers are difficult to determine; fresh water are easier; and salt water filled are quite easy to discern. This applied for soil covers of 6 to 48 in.
- The depth to water table was easily determined by the GPR to a depth of about 12 ft.
- The above observations apply only to plastic containers buried in a low-conductivity, sandy soil. EMI, MAG and MD will probably not work on plastic containers with any type of soil. GPR will, as always, have trouble with high electrical conductivity or inhomogeneous soils.

REFERENCES

- Alongi, A. V. (1973), "Pavement Thickness Measured, Voids Detected by Downward-Looking Radar in New York Test," *Industrial Research News*, Fall 1973, pp. 36-39.
- Annan, A. P. (1973), "Radio Interferometry Depth Sounding: Part I: Theoretical Discussion; Part II: Experimental Results," *Geophysics*, 38, 1973, pp. 557-599.
- R. C. Benson and R. A. Glaccum (1979a), "Remote Assessment of Pollutants in Soil and Groundwater," Proc. of the 1979 Conference on Hazardous Materials Risk Assessment, Disposal and Management, Information Transfer, Inc., Miami Beach, FL, April 1979, pp. 188-194.
- R. C. Benson, R. A. Glaccum (1979b), "Radar Surveys for Geotechnical Site Assessment," Proc. of Conf. on Geophysical Methods in Geotechnical Engineering, Atlanta, Oct. 23-25, 1979, Preprint #3794.
- Bowders, J. J., Jr., Koerner, R. M. and Lord, A. E., Jr. (1982), "Buried Container Detection Using Ground-Probing Radar," *J. Haz. Mater.* 1, pp. 1-17.
- Chan, L. C., D. L. Moffat and L. Peters, Jr. (1979), "A Characterization of Subsurface Radar Targets," Proceedings of the Institute of Electrical and Electronic Engineers, 67, pp. 991-1000.
- Cook, J. C. (1972), "Seeing Through Rock with Radar," Proc. North Amer. Rapid Excavation and Tunneling Conf., pp. 89-101.
- Cook, J. C. (1974), "Ground Probing Radar," Proc. Subsurf. Explor. for Underground Excav. and Heavy Const., ASCE, pp. 172-174.
- Dallaire, G. (1979), "Toxics in the N. J. Environment: Microcosm of U. S. Ills," *Civil Engineering*, ASCE, pp. 74-85.
- Dobrin, M. B. (1976), Introduction to Geophysical Prospecting, McGraw-Hill, New York.
- Dolphin, L. T., R. L. Bollen and G. N. Oetzel (1974), "An Underground Electromagnetic Souder Experiment," *Geophysics* 39, pp. 49-55.
- Ellerbruch, D. A. and J. W. Adams (1974), "Microwave Measurement of Coal Layer Thickness," Final Report NBSIR 74-387, National Bureau of Standards, Boulder, CO, Sept.
- El-Said, M. A. H. (1956), "Geophysical Prospecting of Underground Water in the Desert by Means of Electromagnetic Interference Fringes," *Proceedings, Institute of Radio Engineers*, pp. 24-30.

- Grant, F. S. and G. F. West (1965), Interpretation Theory in Applied Geophysics, McGraw-Hill, New York.
- Griffith, D. H. and R. F. King (1965), Applied Geophysics, Pergamon Press, Oxford.
- Harrison, C. H. (1970), "Reconstruction of Subglacial Relief from Radio Echo Sounding Records," Geophysics 35, 1970, pp. 1099-1115.
- Hart, F. C. (1979), "Preliminary Assessment of Cleanup Costs for National Hazardous Waste Problems," U. S. EPA, Office of Solid Waste, Contract No. 68-01-5063.
- Holser, W. T., R. J. S. Brown, F. A. Roberts, D. C. Fredriksson and R. R. Unterberger (1972), "Radar Logging of Salt Dome," Geophysics 37, pp. 889-906.
- Iddings, F. A., L. W. Miller, C. E. Pepper, and G. A. Keller (1979), "Determination of Cement Content in Soil-Cement Mixtures and Concrete by Neutron Activation Analysis," in Intern. Adv. Nondest. Test. 6, pp. 199-237.
- Kent, G. S. and Wright, R. W. H. (1970), "A Review of Laser Radar Measurements of Atmospheric Properties," Jour. of Atmos. and Terr. Physics 32, pp. 917-943.
- Koerner, R. M., W. M. McCabe and A. E. Lord, Jr. (1973), "Advances in Acoustic Emission Monitoring," Intl. Jour. of Water Power and Dam Const. 30, pp. 38-41.
- Koerner, R. M. and A. E. Lord, Jr. (1976-1981), Monthly Progress Reports to U. S. EPA, Industrial/Environmental Research Laboratory, Edison, NJ, under EPA Cooperative Agreement No. R-804763.
- Koerner, R. M., A. E. Lord, Jr. and W. M. McCabe (1978a), "Acoustic Emission Monitoring of Soil Stability," ASCE Jour. Geotech. Engrn. 104, No. GT5, pp. 571-582.
- Koerner, R. M., A. E. Lord, Jr., T. A. Okrasinski and J. S. Reif (1978b), "Detection of Seepage and Subsurface Flow of Liquids by Microwave Interference Methods," Proc. Conf. on Control of Hazardous Materials, April 11-18, 1978, Miami Beach, Florida, pp. 287-292.
- Koerner, R. M., J. S. Reif and M. J. Burlingame (1979), "Detection Methods for Location of Subsurface Water and Seepage," Journal of the Geotech. Engineering Division, ASCE 105, No. GT11, Proc. Paper 14989, pp. 1301-1316.
- Koerner, R. M., A. E. Lord, Jr. and J. J. Bowders (1981a), "Utilization and Assessment of a Pulsed RF System to Monitor Subsurface Liquids," Proc. of Nat'l. Conf. on Management of Uncontrolled Hazardous Waste Sites, Washington, DC, Oct. 28-30.
- Koerner, R. M. and A. E. Lord, Jr. (1981b), "The Identification and Location of Buried Containers via Nondestructive Testing (NDT) Methods," A State-of-the-Art Review prepared for U. S. EPA Industrial/Environmental Research Laboratory, Edison, NJ.

Koerner, R. M. A. E. Lord, Jr., J. J. Bowders and W. W. Dougherty (1982a), "Use of CW Microwaves to Locate Voids Beneath Paved Areas," ASCE Journal of Construction Division, 108, 133.

Koerner, R. M., A. E. Lord, Jr., S. Tyagi and Brugger, J. E. (1982b), "Use of NDT Methods to Detect Buried Containers in Saturated Silty Clay Soils," Proc. Conf. Management of Uncontrolled Hazardous Waste Sites, Wash., DC, Nov. 29-Dec. 1, 1982, Published by HMCRI, Spring, MD, pp. 12-16.

Koerner, R. M. and A. E. Lord, Jr. (1984), "NDT Location of Containers Buried in Saline Contaminated Soils," Proc. Conf. on Management of Uncontrolled Hazardous Waste Sites, Wash., DC, Nov. 7-9, 1984, Published by HMCRI, Spring, MD, pp. 158-162.

Laine, E. F., K. A. Dines, J. T. Okada, R. J. Lytle (1978), "High Frequency Electromagnetic Probing to Characterize Seals in Cofferdams," Lawrence Livermore Laboratory Report UCRL-82042, August.

Leftwich, R. F. and G. B. Ordway (1970), "Optical Thermal Testing - A State of the Art Review," Inter. J. Nondest. Test 2, pp. 129-170.

Lord, A. E. Jr., Koerner, R. M. and Brugger, J. E. (1980), "Use of Electromagnetic Wave Methods to Locate Subsurface Anomalies," U.S. EPA Nat'l. Conf. on Management of Uncontrolled Hazardous Waste, Oct. 15-17, 1980, Washington, DC, pp. 119-124.

Lord, A. E., Jr. S. Tyagi and R. M. Koerner (1980a), "Non-Destructive Testing (NDT) Methods Applied to Enviromental Problems Involving Hazardous Material Spills," Proc. of Control of Hazardous Materials Spills, May 13-15, 1980, Louisville, Kentucky, pp. 174-179, Publ. by HMRCI, Silver Spring, MD.

Lord, A. E. Jr., R. M. Koerner and J. E. Brugger (1980b), "Use of Electromagnetic Wave Methods to Locate Subsurface Anomalies," Proc. of U.S. EPA Conf. on Managemnet of Uncontrolled Hazardooous Waste Sites, Wash., DC, Oct. 15-17, 1980, Publ. by HMCRI, Silver Spring, MD, pp. 119-124.

Lord, A. E., Jr., S. Tyagi, R. M. Koerner, J. J. Bowders, J. E. Sankey and S. Cohen (1982), "Use of Nondestructive Testing Methods to Detect and Locate Buried Containers Verified by Ground Truth Measurements," Proc. 1982 Hazardous Material Spills Conf., April 19-22, 1982, Milwaukee, Wisconsin, Publ. by Gov't. Inst., Inc., Rockville, MD.

Lord, A. E., Jr., R. M. Koerner and F. J. Freestone (1981a), "The Identification and Location of Buried Containers via Nondestructive Testing Methods," Journal of Hazardous Materials 5, pp. 221-233.

Lord, A. E., Jr., S. Cohen and R. M. Koerner (1981b), "Use of Electrical Resistivity Measurements as a Possible NDT Method Applied to Hazardous Material Spill Problems," Report 10 to U.S. Environmental Protection Agency, Industrial/Environmental Research Laboratory, Oil and Hazardous Material Spills Branch, Edison, NJ on Cooperative Agreement No. CR80777710, August 15, 1981.

Lord, A. E., Jr., S. D. Tyagi and R. M. Koerner (1981c), "Use of Ground Probing Radar and CW Microwave Measurements as Possible NDT Methods Applied to Hazardous Material Spill Problems," Report 13 to EPA, Edison, NJ, on Cooperative Agreement CR80777710, October 1, 1981.

Lord, A. E., Jr., S. D. Tyagi and R. M. Koerner (1981d), "Use of Eddy Currents as a Potential NDT Method Applied to Hazardous Material Spill Problems," Report 2 to EPA on Cooperative Agreement CR80777710, January 6, 1981.

Lord, A. E., Jr., S. D. Tyagi and R. M. Koerner (1981e), "Use of Very Low Frequency-Electromagnetic (VLF-EM) Measurements as a Possible NDT Method Applied to Hazardous Material Spill Problems," Report 8 to EPA on Cooperative Agreement CR80777710, July 4, 1981.

Lord, A. E., Jr., S. D. Tyagi and R. M. Koerner (1981f), "Use of Proton Precession Magnetometer as a Potential NDT Method Applied to Hazardous Material Spill Problems," Report 4 to EPA on Cooperative Agreement CR80777710, February 20, 1981.

Lord, A. E., Jr., R. M. Koerner and F. J. Arland (1984), "The Detection of Containers Located Beneath Water Surfaces Using Nondestructive (Remote) Sensing Techniques," Proc. Conf. on Hazardous Wastes and Environmental Emergencies, Houston, Texas, March 12-14, 1984, Publ. by HMCRI, Silver Spring, MD, pp. 392-395.

Lord, A. E. Jr. and R. M. Koerner (1986a), "Nondestructive Testing (NDT) for Location of Plastic Containers Buried in Soil," Proc. 1986 Hazardous Material Spills Conference, St. Louis, MO, May 5-8, 1986, published by Government Institutes, Inc., Rockville, MD, 20850, pp. 539-545.

Lord, A. E., Jr. and R. M. Koerner (1986b), "Nondestructive Testing (NDT) Location of Containers Buried in Soil," Proc. EPA Conf. on Hazardous Waste, Cincinnati, Ohio, April, pp. 161-169.

Lundien, J. R. (1971), "Terrain Analysis by Electromagnetic Means," Tech. Rpt. 3-693, U. S. Army Waterways Expt. Sta., 34 pgs.

Lundien, J. R. (1972), "Determining Presence, Thickness and Electrical Properties of Stratified Media Using Swept Frequency Radar," Tech. Rpt. M-72-4, U. S. Army Waterways Expt. Sta., 40 pgs.

Lytle, R. J., E. F. Laine, D. L. Lager and D. T. Davis (1979), "Cross-Borehole Electromagnetic Probing to Locate High-Contrast Anomalies," Geophysics, 44, pp. 1667-1676.

McGonnagle, W. J. (1961), Nondestructive Testing, Gordon and Breach Publ., New York.

McNeil, J. D. (1980), "Electromagnetic Terrain Conductivity Measurement at Low Induction Numbers," TN-6, Geonics Ltd., Mississauga, Ontario, Canada, October.

Moffat, D. L. and Puskar, R. J. (1976), "A Subsurface Electromagnetic Pulse Radar," *Geophysics* 41, pp. 406-518.

Morey, R. M. (1974), "Continuous Subsurface Profiling by Impulse Radar," *Proc. Subsurf. Explor. for Underground Excav. and Heavy Const.*, ASCE, pp. 213-232.

Okrasinski, T. A., A. E. Lord, Jr. and R. M. Koerner (1978), "Laboratory Determination of Subsurface Water Levels Using Microwave Interference," *ASCE Jour. Geotech. Engrg.* 104, No. GT 1, pp. 119-124.

Okrasinski, T. A., R. M. Koerner and A. E. Lord, Jr. (1979), "Dielectric Constant Determination of Soils at L-Band Microwave Frequencies," *Geotech. Test. Jour.*, ASTM, 1, pp. 134-140.

Rosetta, J. V. (1977), "Detection of Subsurface Cavities by Ground Probing Radar," *Proc. Symp. Detect. Subsurf. Cavities*, U. S. Waterways Exp. Sta., Vicksburg, MS, pp. 120-127.

Rubin, L. A., J. N. Griffin and W. L. Still (1976), "Subsurface Site Investigation by Electromagnetic Radar, Phase I Report: Feasibility," Report NSF/RA-76-0187, ENSCO, Inc., Springfield, VA, March.

Rubin, L. A. and J. C. Fowler (1978), "Ground-Probing Radar for Delineation of Rock Features," *Engineering Geology* 12, pp. 163-170.

Sandness, G. A., G. W. Dawson, T. J. Mathieu and J. L. Rising (1979), "The Application of Geophysical Survey Techniques to Mapping of Wastes in Abandoned Landfills," *Proc. of the 1979 Conference on Hazardous Materials Risk Assessment, Disposal and Management*, Information Transfer, Inc., Miami, Beach, FL, April 1979.

Sharma, P. V. (1976), *Geophysical Methods in Geology*, Elsevier, Amsterdam.

Sharpe, R. S. (1970), *Research Techniques in Nondestructive Testing*, Academic Press, New York.

HRB-Singer, Inc. (1971) State College, PA, "Detection of Abandoned Underground Coal Mines by Geophysical Methods," U. S. EPA and PA Dept. of Environ. Res., Project 14010, Report EHN.

Tyagi, S., Lord, A. E., Jr. and Koerner, R. M. (1983a), "Use of a Metal Detector to Detect Buried Drums in Sandy Soil," *J. Haz. Mater.* 1, pp. 375-381.

Tyagi, S., Lord, A. E., Jr. and Koerner, R. M. (1983b), "Use of a Very Low Frequency Electromagnetic Method at 9.5 KHz to Detect Buried Drums in Sandy Soil," *J. Haz. Mater.* 1, pp. 353-373.

Tyagi, S., Lord, A. E., Jr. and Koerner, R. M. (1983c), "Use of a Proton Precession Magnetometer to Detect Buried Drums in Sandy Soils," *J. Haz. Mater.* 2, pp. 11-19.

Unterberger, R. R. (1974), "Electromagnetic Wave Propagation in Rock Salt," in Proc. of the Fourth Symposium on Salt, North Ohio Geological Society, Columbus, Ohio.

Unterberger, R. R. (1977), "Overview of Electromagnetic Methods in Geophysics and Application of Radar to Detection of Cavities in Salt," in Symposium on Detection of Subsurface Cavities by Surface Remote Sensing Techniques, U.S. Army Waterways Experiment Station, Vicksburg, MS, p. 119.

Van Reenan, E. D. (1964), "Subsurface Exploration by Sonar Seismic Systems," in Soil Exploration, ASTM Special Tech. Publ., No. 351, p. 60-73.

Weston (1981), "Ground Penetrating Radar Survey, Elizabeth, NJ," Weston Consultants Final Report to USCG, New York, NY, Jan. 30, 1981.

APPENDICES

APPENDIX A - UNIT CONVERSION CHART

<u>Quantity Given In</u>	<u>MKS (SI) Unit</u>	<u>Conversion to MKS Unit</u>
gallon	m ³	multiply by 3.79x10 ⁻³
feet	m	" " 0.3048
cubic yard	cubic meter	" " 0.765
inches	m	" " 2.54x10 ⁻²
lb/ft ³	N/m ³	" " 157
gammas	Teslas	" " 10 ⁻⁹
cm ² /sec	m ² /sec	" " 10 ⁻⁴

APPENDIX B - LIST OF REPORTS SUBMITTED IN THIS PROJECT

<u>Number</u>	<u>Topic</u>	<u>Date</u>
1	Infrared Sensing	December 22, 1980
2	Eddy Currents	January 6, 1981
3	Penetrating Radiation	January 30, 1981
4	Proton Precession Magnetometer	February 20, 1981
5	Surface Coating Technique	March 20, 1981
6	Ultrasonics	May 11, 1981
7	Electrical Potential	June 5, 1981
8	VLF-EM Resistivity	July 6, 1981
9	Induced Polarization	July 24, 1981
10	DC - Resistivity	August 15, 1981
11	Sonar	August 20, 1981
12	Acoustic Emission	August 25, 1981
13	Ground Probing Radar with CW Microwaves	November 16, 1981
14	Seismic	April 15, 1982
15	Groundwater Flow	July 21, 1982
16	A Simple, Physical Calculation of the Response of a Buried Conducting Drum to Electromagnetic Induction Searching	October 7, 1982
17	Use of a Metal Detector to Detect Buried Drums in Sandy Soil	January 3, 1983
17a	Informal Report - A Field Site with Controlled Flow for Seepage Plume Monitoring	March 8, 1983
18	Buried Container Detection Using Ground Probing Radar (GPR)	April 12, 1983

19	Use of an Electromagnetic Method (VLF) at 9.5 KHz to Detect Buried Drums in Sandy Soil	July 13, 1983
20	Use of a Proton Precession Magnetometer to Detect Buried Drums in Sandy Soils	September 21, 1983
21	Use of NDT Methods to Detect and Locate Buried Containers Verified by Ground Truth Measurements	May 15, 1984
22	Use of NDT Methods to Detect Buried Containers in Saturated Silty Clay Soil	July 24, 1984
23	Sensitivity Study of a Ground Probing Radar System	November 14, 1984
24	The Detection of Containers Located Beneath Water Surfaces Using Nondestructive (Remote Sensing) Techniques	February 15, 1985
25	Laboratory Leak Detection in Gas and Liquid Storage Tanks Using Continuous Wave Acoustic Emissions	April 30, 1985
26	NDT Location of Containers Buried in Saline Contaminated Soils	July 30, 1985
27	Signal Processing (Background Removal) with the Ground Penetrating Radar	October 15, 1985
28	NDT Location of Plastic Containers Buried in Soil	January 29, 1986
29	Very Inexpensive Organic Vapor Detection Applied to the Leaking Underground Tank Problem	April 1, 1986

APPENDIX C - CALCULATION OF SOIL SURFACE TEMPERATURE DISTRIBUTION DUE TO BURIED OBJECTS AT SLIGHTLY ELEVATED TEMPERATURE

At this point we are interested in the simplest calculation which has some physical relevance to the problem of infrared (IR) detection of a buried object which is at a temperature different from its surroundings. This calculation is performed to get first estimates as to whether (IR) techniques will be of value in detecting buried containers, which under certain conditions might be a few degrees above or below ambient. The model is shown in Figure 1. A spherical body of radius R at temperature T_s is placed in an infinite body of temperature T_o ($T_s > T_o$). The temperature of the sphere is maintained at T_s (from time zero) for all time. The temperature at any point r is given by (Reference 1)

$$T = \frac{T_s R}{r} (1 - \Phi[(r-R)\eta]) \quad (1)$$

where Φ is the probability integral (error function) and $\eta = 1/2\sqrt{\alpha t}$, with α the thermal diffusivity and "t" the time. We assume the surface of the earth (represented by the dashed line in Figure 1) presents no resistance to heat flow, i.e., we can use the infinite body solution even in the presence of the surface. If this was not so, the calculation would be most difficult. We shall present temperature data along the surface to ascertain whether large enough temperature gradients are present at the surface to detect with current (IR) techniques.

We shall assume a one foot (30 cm) radius sphere buried at depths of one foot (30 cm) and three feet (90 cm). This is the depth to the top of the sphere. The thermal diffusivity is taken as 3.6×10^{-3} in cgs units*, a typical value for soil.¹ It is assumed that for some reason (internal heat generation, differential heating under sun's rays, etc.) that the temperature of the sphere is 2° above that of the soil. The results of the calculation are shown in Figures 2 and 3. The horizontal temperature distribution is shown at different times. For times less than those shown on the figures, the temperature rises were below detection limits.

The temperature resolution of a typical infrared unit is 0.1 - 0.2°C. Thus for our model situation, it probably would be possible to detect (with some difficulty) the sphere at a depth of 30 cm (1 ft) but not at a depth of 90 cm (3 ft) i.e., the temperature gradients in Figure 3 are not large enough to detect.

If the surface represents a significant barrier to heat flow, then heat will "bunch-up" at the surface and decrease the temperature gradients, making (IR) detection more difficult. As time increases, Figure 2 and 3 show that the temperature gradients decrease. Thus for very long times the gradients will probably become too small to be of value in IR sensing. If the temperature of the buried object is significantly higher (or lower) than its surroundings then (IR) sensing will be correspondingly easier.

*This is in cm^2/sec .

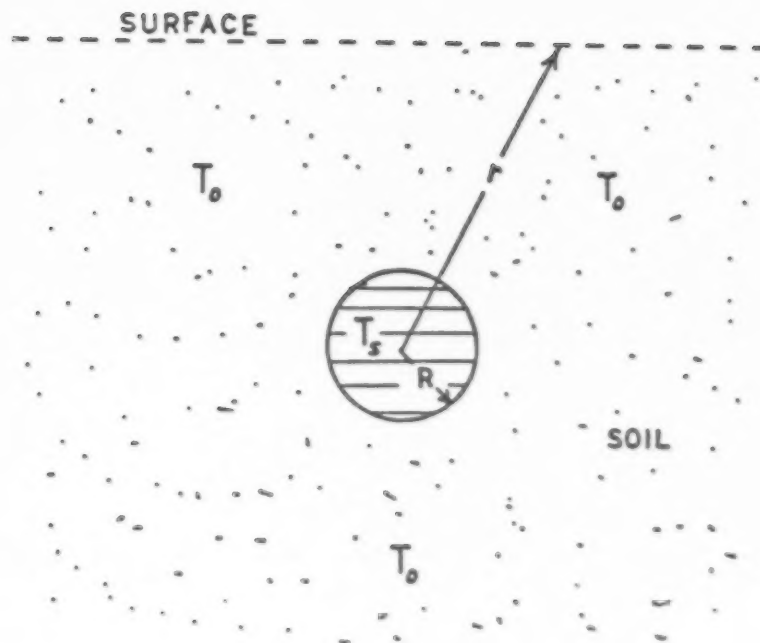


Figure C-1 - Schematic Diagram of Situation.

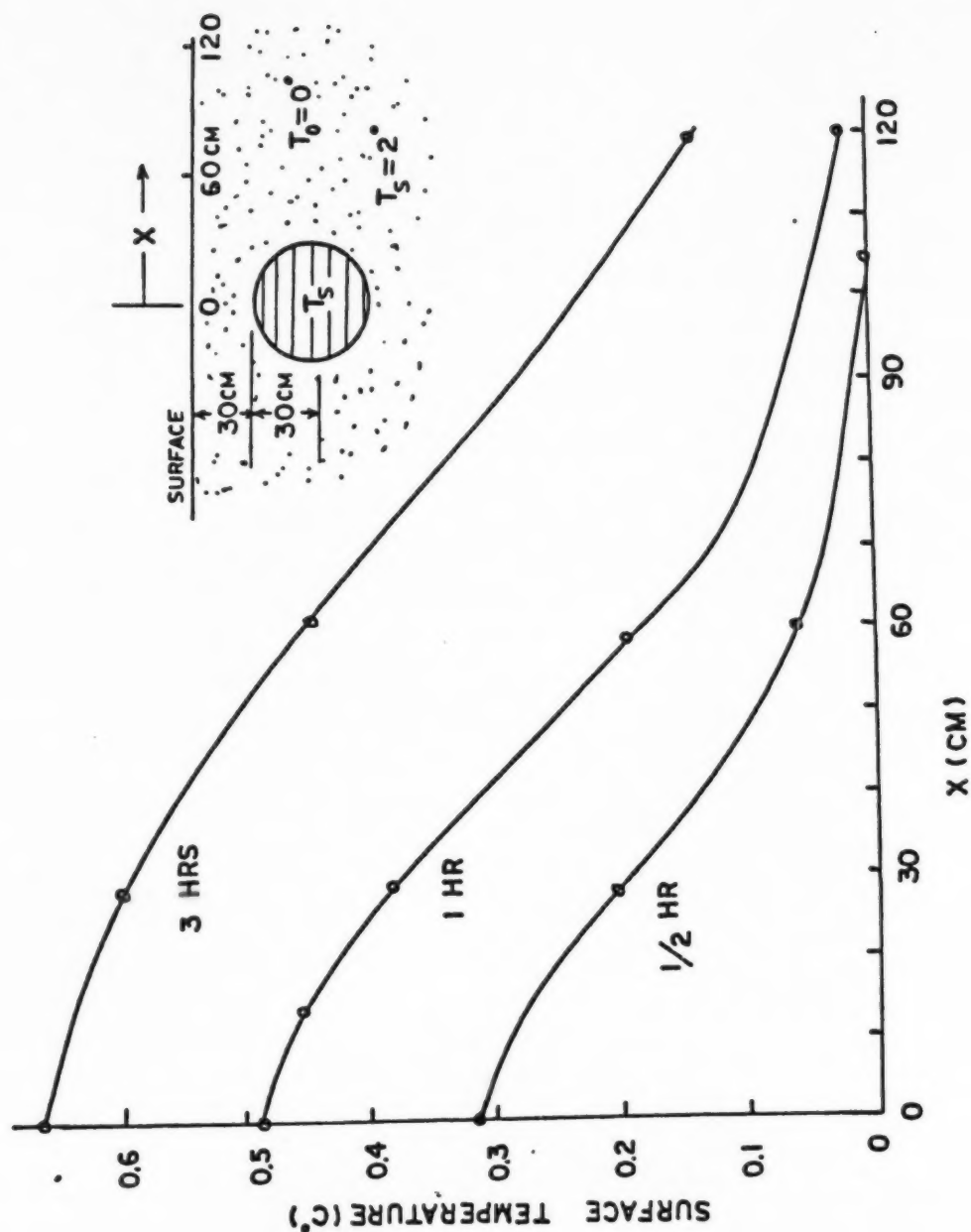


Figure C-2 - Surface Temperature for Sphere Buried at 30 cm.

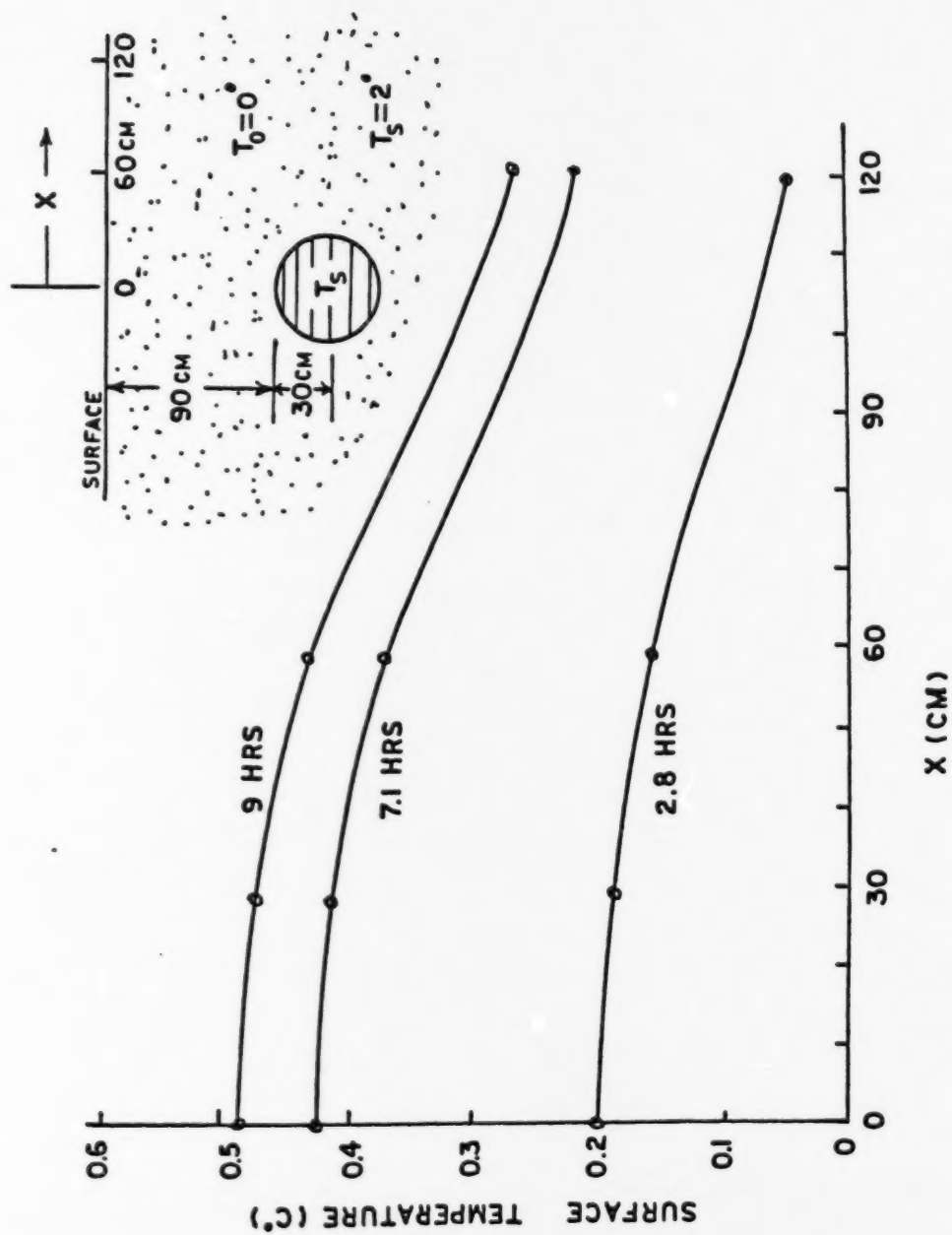


Figure C-3 - Surface Temperature for Sphere Buried at 90 cm.

These calculations are for an admittedly crude model and meant to give only order of magnitude results. It is possible in the future that we will perform more realistic calculations, as time permits. However, it is felt that with no work of this type immediately available, these will serve as the initial source of ideas.

1. L. R. Ingersoll, O. J. Zobel and A. C. Ingersoll, Heat Conduction with Engineering and Geological Applications, McGraw Hill, New York, 1948, p. 142.